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NHRI PAPER NO. 38

IWD TECHNICAL BULLETIN NO. 154

Water Use in the Coal Mining Industry and its Influence on Ground Water in Western Canada

W.B. Barrie and C.H. Carr

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INLAND WATERS DIRECTORATE
SASKATOON, SASKATCHEWAN
and
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OTTAWA, CANADA, 1988

(Disponible en français sur demande)

88-03683/



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This report was written under contract for the National Hydrology Research Institute and the Environmental Protection Service of Environment Canada. It was funded by the Office of Energy Research and Development (Energy, Mines and Resources Canada)/Panel on Energy Research and Development (PERD) under Task 24201 "Environmental Protection Criteria for Coal Mining and Processing." Part A was written by W.B. Barrie and Associates and the Industrial Programs Branch, Environmental Protection, Environment Canada. Part B was coauthored by W.B. Barrie and C.H. Carr.

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Published by authority of
the Minister of the Environment

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Cat. No. En 36-503/154E

ISBN 0-662-16015-0

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Abstract

Coal production in Canada has increased dramatically since 1970, and although growth slowed unexpectedly during the early 1980s, most experts estimate that production will increase twofold by the year 2000. Approximately 90% of the total Canadian thermal and metallurgical coal production in 1985 (60.5 million tonnes) came from British Columbia, Alberta and Saskatchewan; it is anticipated that the domination of Western Canada in total coal production will continue to the year 2000.

Water is required in large quantities for the mining and preparation of coal, and concerns have been raised over the environmental and economic implications of coal industry expansion in Western Canada. This report presents the findings of two studies which examine water supply and demand in Western Canada; these studies were initiated to assist in the development of environmental protection criteria and/or technologies to ensure that Western Canadian ground-water systems will not be adversely affected by new or expanding coal mining and preparation facilities.

The first study assesses water demands for present and planned coal mining and preparation activities in Western Canada and identifies existing and potential water supply problems due to water use by the coal industry. Minimum, maximum and most probable water quantity requirements of the coal industry for the year 1990 are forecast based on (i) coal demand by type (thermal or metallurgical) and location (physiographic province), (ii) current water requirements for coal mining and preparation by coal type, and (iii) water requirements for new coal technologies such as coal conversion and coal slurry pipelines. The future water requirements of the coal industry are assessed in relation to the probable demands that would be generated by other sectors of the economy.

The second study identifies and appraises the ground-water resources of the coal-producing regions and assesses the influence of coal mining and preparation on local and regional ground-water systems before, during and after mining.

In general, the ability of surface and ground-water resources to meet water demands decreases from west to east in Western Canada. Ground-water quality also tends to decrease from west to east, with a number of specific problems occurring in Alberta and Saskatchewan such as high levels of nitrate, iron, fluoride, sulphide and sodium; high concentrations of total dissolved solids are a particular problem in Saskatchewan.

Pre-mining impacts on the distribution and quality of ground water are most evident in the foothills and mountains of British Columbia and Alberta; impacts during mining are evident throughout all the coal producing regions and post-mining impacts are most likely to be problematic in the plains regions of Alberta and Saskatchewan.

Water use for coal mining and preparation is the greatest at mines in British Columbia and Alberta where most of the coal is wet-processed at or near the mine site. Using the most probable coal production scenario for the year 1990, water demands are expected to increase in each region as follows: (i) 12.3 million cubic metres in 1983 to 28.8 million in 1990 for the foothills and mountains region of British Columbia and Alberta, (ii) 0.15 million cubic metres in 1983 to 2.1 million in 1990 for the Plains region of Alberta, and (iii) 0.1 million cubic metres in 1983 to 0.08 million cubic metres in 1990 in the Plains region of Saskatchewan.

There is evidence of existing and potential water supply problems in the Plains regions of Alberta and Saskatchewan; current and planned coal developments occur in basins that are water short or are experiencing pent-up demands and face potential water shortages by the year 2000.

Résumé

La production houillère au Canada a augmenté considérablement depuis 1970. Même si la croissance a ralenti de façon imprévue au début des années 1980, la plupart des experts estiment que la production aura doublé en l'an 2000. En 1985, environ 90 % de toute la production de charbon de chauffage et de charbon à coke (60.5 millions de tonnes) provenaient de la Colombie-Britannique, de l'Alberta et de la Saskatchewan. On croit que la prépondérance de l'Ouest du Canada pour l'ensemble de la production houillère se poursuivra jusqu'en l'an 2000.

On utilise de grandes quantités d'eau dans l'extraction et la préparation de la houille. A cet égard, les incidences environnementales et économiques de l'expansion de l'industrie houillère dans l'Ouest du Canada ont soulevé des inquiétudes. Ce rapport présente les résultats de deux études qui examinent l'approvisionnement et la demande en eau dans l'Ouest du Canada. Le but de ces études est d'aider à élaborer des critères ou des techniques de protection environnementale qui empêcheront la perturbation des réseaux d'eau souterraine de l'Ouest du Canada par les installations de préparation et d'extraction houillères, nouvelles ou en voie d'expansion.

La première étude évalue la demande en eau actuelle et future en fonction des activités de préparation et d'extraction houillères dans l'Ouest du Canada. Elle analyse les problèmes réels ou éventuels relatifs à l'approvisionnement en eau, qui surgissent dans l'utilisation de l'eau par l'industrie houillère. L'évaluation des besoins en eau (minimum, maximum et moyenne probable) de l'industrie houillère pour l'année 1990 dépend des facteurs suivants : i) la demande houillère selon le type (charbon de chauffage ou charbon à coke) et l'emplacement (province physiographique); ii) les besoins en eau actuels pour la préparation et l'extraction houillères selon le type de charbon; iii) les besoins en eau des nouvelles techniques houillères comme la transformation houillère et les hydrocarbures. Dans l'avenir, les demandes en eau de l'industrie houillère seront évaluées en fonction des demandes probables des autres secteurs de l'économie.

La deuxième étude détermine et évalue les ressources en eau souterraine des régions productrices de houille. Elle évalue aussi l'influence de la préparation et de l'extraction houillères sur les réseaux locaux et régionaux d'eau souterraine avant, pendant et après l'extraction.

En règle générale dans l'Ouest du Canada, la possibilité de répondre à la demande en eau, souterraine ou de surface, diminue d'ouest en est. La qualité de l'eau souterraine diminue également d'ouest en est, puisqu'on constate en Alberta et en Saskatchewan, la présence de certains problèmes précis comme la forte teneur de nitrate, de fer, de fluorure, de sulfure et de sodium. Les concentrations élevées de matières totales dissoutes constituent aussi un problème particulier en Saskatchewan.

Les travaux précédant l'extraction minière ont des répercussions sur la répartition et la qualité de l'eau souterraine en particulier dans les avant-monts et les montagnes de la Colombie-Britannique et de l'Alberta. Les répercussions durant l'extraction minière se font sentir dans toutes les régions productrices de houille. Enfin, les répercussions qui surviennent après l'extraction se font vraisemblablement sentir dans les plaines de l'Alberta et de la Saskatchewan.

C'est dans les mines de la Colombie-Britannique et de l'Alberta qu'on utilise la plus grande quantité d'eau pour l'extraction et la préparation houillère. En effet, la majeure partie du charbon y est traitée par voie humide, à la mine même ou près de celle-ci. A la lumière du scénario de production houillère le plus probable pour l'année 1990, on évalue les demandes en eau dans chacune des régions comme suit : i) de 12.3 millions de mètres cubes en 1983 elles passeront à 28.8 millions en 1990 dans la région des avant-monts et des montagnes de la Colombie-Britannique et de l'Alberta; ii) de 0.15 million de mètres cubes en 1983 elles passeront à 2.1 millions en 1990 dans la région des plaines de l'Alberta; iii) de 0.1 million de mètres cubes en 1983 elles passeront à 0.08 million de mètres cubes en 1990 dans la région des plaines de la Saskatchewan.

Il est clair qu'il existe dans les régions des plaines de l'Alberta et de la Saskatchewan des problèmes réels et éventuels relatifs à

l'approvisionnement en eau. L'exploitation houillère actuelle et future se trouve dans des bassins qui manquent d'eau ou qui connaissent des demandes accumulées et risquent de manquer d'eau vers l'an 2000.

Executive Summary

This summary presents the findings of two reports commissioned by the Inland Waters Directorate and Environmental Protection Programs Directorate of Environment Canada as part of a study entitled "Development of Environmental Protection Criteria for the Design and Operation of New and Expanding Coal Mining and Processing Facilities." The study objectives are listed below, followed by a description of the study area. Then a synopsis of each report is given.

STUDY OBJECTIVES

Part A. Water Use: Current and Forecast

1. Examine water use at coal mines and preparation plants in Western Canada and estimate current demands for water per tonne of product coal.
2. Estimate the demand for Western Canadian thermal and metallurgical coal for the year 1990.
3. Forecast water demands for the coal industry in Western Canada for the year 1990 using low, medium and high production scenarios.
4. Review the likelihood of implementation of new coal technologies in Western Canada by the year 1990 and estimate water requirements.
5. Identify existing and potential water supply problems in Western Canada due to water use by the coal industry.

Part B. Influence on Ground Water

1. Provide a general characterization of the hydrogeologic environments in the areas of current and potential coal facilities in Western Canada.
2. Assess the influence of coal mining and preparation on local and regional ground-water systems before, during and after mining.

STUDY AREA

This study focusses exclusively on coal mining in Western Canada. The study area was divided into three coal-producing regions:

- (1) The Rocky Mountains of British Columbia and the mountains and Foothills of Alberta.
- (2) The Plains of Alberta.
- (3) The Plains of Saskatchewan and Manitoba.

PART A. WATER USE: CURRENT AND FORECAST

1. Major Uses of Water in the Coal Industry

The major uses of water at a coal mine development are for coal preparation, dust suppression, equipment maintenance and sanitation. The amount of water required depends on the nature and degree of coal preparation, the form of coal extraction, either surface or underground, and the amount of ancillary activity. Water use for coal-fired thermal electric power generation was not included as part of mine and preparation plant water use. It is important to note, however, that many of the mines in Regions 2 and 3 have mine mouth power plants that require approximately 27 million cubic metres of water annually per thousand megawatts installed capacity.

Coal Preparation

The wet preparation of thermal and metallurgical coals in Region 1 requires significant amounts of water; thermal coals in Regions 2 and 3 are dry-processed by crushing and screening with no requirement for water.

Dust Suppression

Little is known about the use of water or other agents for dust suppression at coal mines in Western Canada. Strip mines in Regions 2 and 3 affect much larger land surface areas than open pit mines in Region 1 and

require larger quantities of water for dust suppression. It is estimated that dust suppression at strip mines in Saskatchewan consumes 90% of the total water intake.

Equipment Maintenance and Sanitation

All mines require water for sanitary use and equipment maintenance; the amounts required are site specific, depending on the size and operating schedule of the work force and on the type and amount of equipment used. Approximately 4% of the total annual water intake is required for equipment maintenance at an open pit mine in southeastern British Columbia (Region 1). A design figure of 320 L/day per employee is assumed for sanitary water use.

2. Current Coal Production and Water Use (1983)

Region 1

There are three principal coal-producing areas in Region 1 with 14 operating mines and 13 wet preparation plants. Approximately six million tonnes of thermal coal and 14 million tonnes of metallurgical coal were produced during 1983. All thermal coal was extracted from open pits; 89% of the metallurgical coal was extracted from open pits and the remaining 11%, from underground workings.

It is estimated that 12.3 million cubic metres of water was used to mine and prepare coal in the region during 1983. This represents approximately 24% of total water use in the region by all sectors.

Water use in the three coal-producing areas is as follows:

- (a) Wolverine area, northeastern British Columbia: water was used at a rate of approximately $0.4 \text{ m}^3/\text{t}$ of product coal for a total of $136\,000 \text{ m}^3$; most of this water was derived from surface sources.
- (b) Yellowhead area, west-central Alberta: water use ranged from 0.33 to $1.85 \text{ m}^3/\text{t}$ of product coal for a total of 5.1 million cubic metres; both surface and ground-water sources were used.

- (c) East Kootenay area, southeastern British Columbia: water use ranged from 0.06 to 0.86 m³/t of product coal for a total of 7 million cubic metres; both surface and ground-water sources were used.

Region 2

There are two principal coal-producing areas in Region 2 with six operating mines. Approximately 14 million tonnes of thermal coal was produced during 1983 from strip mines in the Lake Wabamun area west of Edmonton and the Forestburg/Halkirk area southeast of Edmonton.

It is estimated that water was used at a rate of 0.01 m³/t of product coal to give a total of 144 300 m³. This represents less than 1% of total water use by all sectors in the region during 1983. Water was obtained primarily from surface sources. Approximately 90% of the water was used for dust suppression.

Region 3

There are two principal coal-producing areas in Region 3 with six operating mines. Approximately 8 million tonnes of thermal coal was produced during 1983 from strip mines in the Estevan area of southeastern Saskatchewan and the Coronach area of south-central Saskatchewan.

It is estimated that water was used at a rate of 0.01 m³/t of product coal to give a total of 77 550 m³. This represents less than 1% of total water use by all sectors in the region during 1983. In the Estevan area 90% of the water was obtained from surface sources and 10% from public utility systems. The Poplar River Mine in the Coronach area obtained all of its water from ground water. Approximately 90% of the water was used for dust suppression.

3. Coal Production and Water Use Forecasts

Low, medium and high coal production and water use scenarios for each region for the year 1990 are summarized in this section. The scenarios

are defined as follows:

- (a) Low scenario: minimum estimated water requirement
(best case)
- (b) Medium scenario: most probable estimated water requirement
- (c) High scenario: maximum estimated water requirement
(worst case).

Region 1

The *low scenario* assumes that no new mines will be developed in Region 1 with increased coal production as a result of the expansion of existing facilities. The production of thermal coal will increase from 6 million tonnes in 1983 to 14 million tonnes in 1990; metallurgical coal will increase from 14 to 18 million tonnes. It is estimated that water use will increase by 46% over 1983 levels, with a total annual requirement of 17.9 million cubic metres.

The *medium scenario* assumes one new mine development in northeastern British Columbia and greater expansion of existing facilities than indicated in the low scenario. Thermal coal production will increase from 6 million tonnes in 1983 to 15 million tonnes in 1990; metallurgical coal output will increase from 14 to 20 million tonnes. It is estimated that water use will increase by 142% over 1983 levels with a total annual requirement of 29.9 million cubic metres, including 10.5 million cubic metres for a coal/water slurry pipeline.

The *high scenario* assumes extensive new mine development in northeastern and southeastern British Columbia and in the Yellowhead area of Alberta, in addition to increased production from existing facilities. Thermal coal production will increase from 6 million tonnes in 1983 to 45 million tonnes in 1990; metallurgical coal will increase from 14 to 40 million tonnes. It is estimated that water use will increase by 393% over 1983 levels with a total annual requirement of 60.8 million cubic metres, including 18.7 million cubic metres for slurry pipeline water use.

Region 2

The *low scenario* assumes that two new mines will be developed in Region 2 and existing facilities will increase production at an average rate of 5.5% annually until 1990. Thermal coal production will increase from 14 million tonnes in 1983 to 21 million tonnes in 1990. It is estimated that water use will increase by 46% over 1983 levels with a total annual requirement of 210 500 m³.

The *medium scenario* assumes that four new mines will be developed in the region and existing facilities will increase production at an average rate of 5.5% annually until 1990. Thermal coal production will increase from 14 million tonnes in 1983 to 27 million tonnes in 1990. Coal from two of the new mines will require wet preparation resulting in a significant increase in water use for the region. It is estimated that the increase in water use will be 1420% over 1983 levels with a total annual requirement of 2.1 million cubic metres.

The *high scenario* assumes extensive new mine development in the region and increased production at existing facilities at an average rate of 5.5% annually until 1990. Thermal coal production will increase from 14 million tonnes in 1983 to 47 million tonnes in 1990. Coal from five new mines in the region will require wet preparation and water use will increase significantly. It is estimated that the increase in water use will be 2820% over 1983 levels, with a total annual requirement of 4.2 million cubic metres.

Region 3

The *low scenario* assumes that one new mine will be developed in Region 3 and existing facilities will increase production at an average rate of 3% annually until 1990. It is estimated that water use will increase by 23% over 1983 levels, with a total annual requirement of 95 300 m³.

The *medium scenario* assumes that one new mine will be developed and existing facilities will increase production at an average rate of 3% annually until 1990. Thermal coal production will increase from 8 million

tonnes in 1983 to 10 million tonnes in 1990. It is estimated that water use will increase by 32% over 1983 levels with a total annual requirement of 102 000 m³.

The *high scenario* assumes that two new mines will be developed and existing facilities will increase production at an average rate of 3% annually until 1990. Thermal coal production will increase from 8 million tonnes in 1983 to 12 million tonnes in 1990. It is estimated that water use will increase by 56% over 1983 levels, with a total annual requirement of 120 600 m³.

4. New Coal Technologies

The water requirements and likelihood of implementation of the following new coal technologies in the study area by 1990 are examined:

- (a) coal slurry pipelines
- (b) flue gas desulphurization
- (c) advanced coal preparation
- (d) coal liquefaction and gasification.

Coal Slurry Pipelines

Two long distance slurry pipelines have been proposed for the transportation of coal from the Yellowhead area of Region 1 to the west coast of British Columbia for export to countries in the Pacific Rim. There is also considerable interest in using the Trans-Mountain oil pipeline, which currently transports oil from Edmonton to Vancouver, as a dual-mode pipeline to batch transport both crude oil and coal slurries.

Between 0.9 and 1.0 m³ of water is required to transport one tonne of coal in a slurry consisting of 50% coal and 50% water by weight.

The *medium scenario* assumes that a coal slurry pipeline will become operational in Region 1 by 1990. It is estimated that 10.2 million

tonnes of coal will be transported annually with a total water requirement of 10.5 million cubic metres; the *high scenario* assumes a greater throughput of approximately 18.2 million tonnes of coal with a total annual water requirement of 18.7 million cubic metres.

Flue Gas Desulphurization

It is estimated that a wet flue gas desulphurization system installed in a 600-MW coal-fired thermal power plant would require 0.27 m^3 of water per tonne of coal input or 810 000 m^3/yr . It is assumed that future power plants in the study area will exist in the current form with no utilization of flue gas desulphurization processes by the year 1990 or 2000.

Advanced Coal Preparation

Potential advanced coal preparation may comprise physical, chemical and biological coal cleaning technologies. From 1990 to the year 2000, conventional physical coal cleaning, as it exists today, will still be practised. However, the operations will be increasingly refined with possible lower water consumption. Biological and chemical coal cleaning processes are not expected to be operational in the study area by 1990.

Coal Liquefaction and Gasification

Water use is estimated at $0.97 \text{ m}^3/\text{t}$ of coal input for direct liquefaction and $2.63 \text{ m}^3/\text{t}$ of coal input for indirect liquefaction. An indirect liquefaction pilot plant is expected to be in operation in early 1987 near Edmonton (Region 2), and two commercial plants are expected in the same area in the 1990s. Water use for both commercial plants may reach 36.4 million cubic metres per year.

Water use for coal gasification using the Lurgi process is estimated at $1.18 \text{ m}^3/\text{t}$ of coal input. It is unlikely that a commercial coal gasification plant will be operating in the study area by the year 1990 or 2000.

5. Existing and Potential Water Supply Problems

Region 1

Although current and potential coal developments rank high as a water-using sector, there is a sufficient supply of water in the region to meet anticipated demands. Offstream storage during low flow periods may be required to meet water demands in the Foothills zone of Alberta.

Region 2

Coal developments are planned for the water short Oldman River sub-basin and for the Red Deer River sub-basin which is currently experiencing pent-up demands and facing potential water shortages by the year 2000. Proposed development in the Oldman sub-basin includes two underground mines and two wet preparation plants under the medium scenario and a third underground mine and wet preparation plant under the high scenario. Development in the Red Deer sub-basin includes a surface mine under the medium scenario and two underground mines under the high scenario. A thermal electric generating station is to commence operation in 1985/86.

An estimated 17 thermal electric generating stations are planned for the region by the year 2000. Most will be mine mouth plants requiring approximately 27 million cubic metres of water annually per 1000-MW installed capacity.

Region 3

Coal developments are planned for the water short Souris River sub-basin and for the Poplar River, Frenchman River and Swift Current Creek sub-basins which are currently experiencing pent-up demands.

The continued operation of coal mines and thermal electric generating stations in the Souris River sub-basin may contribute to a lowering of ground-water levels in the Estevan aquifer. Two additional generating stations are planned for the sub-basin by the year 1990.

Operation of the Poplar River thermal electric generating station in the Poplar River sub-basin results in diminished surface and ground-water supply; dewatering of the coal seam at the Poplar River mine has extended the ground-water cone of depression to within 800 m of the Canada/United States border.

A surface mine is planned for the Swift Current Creek/Frenchman River sub-basin under the high scenario. These sub-basins have practised apportionment and rationing of water supplies for many years and further industrial development may not be possible.

PART B. INFLUENCE ON GROUND WATER

1. Ground-Water Occurrence and Quality

Region 1

The ground-water potential in much of Region 1 is unknown. In addition to large volumes of good quality surface water, however, there are numerous high-yielding alluvial, colluvial and karstic aquifers of limited extent but with high recharge capability, evenly distributed throughout the region.

Bedrock in the region is generally believed to have poor ground-water potential, with wells producing less than 0.5 L/s.

Coal deposits in northeastern British Columbia are high-yielding aquifers; deposits in southeastern British Columbia behave as aquicludes and are, therefore, low-yielding.

Flow rates up to 75 L/s have been measured at springs emanating from karstic carbonates in topographic lows.

Surficial deposits on the floors and lower slopes of intermontane valleys provide the best natural aquifers in Region 1. Permeable sand and gravel deposits typically produce flows of 8 to 40 L/s.

In general, ground waters in Region 1 are low in mineral content and hardness. Major constituents in the water are Ca^{2+} , Mg^{2+} , HCO_3^- and CO_3^{2-} ; total dissolved solids concentrations range from 50 to 500 mg/L.

Region 2

The ability of surface and ground-water resources to meet water demand decreases eastward in Region 2. Thick, laterally continuous, flat-lying sedimentary rocks provide a significant water storage capacity in Region 2. The best aquifers with their yields (L/s) are listed in the table below.

Horseshoe Canyon coals (central Alberta)	2-8
Paskapoo sandstone (west-central Alberta)	8-35
Millet sandstone (southwest of Edmonton)	7.6
Milk River sandstone (southwestern Alberta)	0.4-40

The most important surficial aquifers in Region 2 are

- (a) Preglacial valley sands and gravels with yields typically 5 to 10 L/s but up to 40 L/s in the southwest part of the region
- (b) Glacial outwash with yields of 0.4 to 2.0 L/s near Medicine Hat
- (c) Intertill sand and gravel lenses with yields of 2 to 8 L/s near Wabamun
- (d) Recent river alluvium with yields typically greater than 8 L/s but up to 40 L/s.

Coal deposits in the region behave as aquifers whose yields are controlled by the degree of fracturing of the coal; sustainable yields of from 2 to 8 L/s were obtained for coal aquifers in the Edmonton area (Horseshoe Canyon Formation).

Ground-water quality is generally good in Region 2 but exhibits a trend toward decreasing quality from west to east. Specific problems are as follows:

- (a) High nitrate levels occur at shallow depths throughout the region

- (b) Iron and fluoride levels locally exceed recommended drinking water standards in the western part of the region
- (c) Sulphide and sodium levels and alkalinity may exceed recommended drinking water standards in the eastern part of the region.

The concentration of total dissolved solids in the bedrock aquifers increases with depth and age of formation, and ranges from less than 100 mg/L in recharge areas of the Paskapoo Formation to greater than 4000 mg/L in the eastern part of the Milk River Formation. Chemical constituents in the water trend from Ca^{2+} , HCO_3^- and CO_3^{2-} ; in the west to Na^+ and SO_4^{2-} in the east.

Little is known about the quality of ground water in coals of the region.

Water quality in surficial deposits is generally very good where there is moderate flow; where flow is sluggish the concentration of total dissolved solids can be very high. In recharge areas concentrations are less than 1500 mg/L, with Ca^{2+} , Mg^{2+} and HCO_3^- as the dominant ions; in the intermediate flow systems and discharge areas concentrations increase to 2500 mg/L and Na^+ , SO_4^{2-} and Cl^- are the dominant ions.

Region 3

There is very little surface water supply in Region 3 and only one major aquifer system.

Although the bedrock formations of the region provide a significant water storage capacity, none is capable of producing 8 L/s of water with total dissolved solids concentrations of less than 4000 mg/L.

The hydrogeology of coal deposits in the region is not well known.

The Estevan aquifer system in the southeast corner of Saskatchewan is the only major aquifer in the region. It is composed of the hydraulically continuous Estevan and Weyburn Valley aquifers and the sand and coal beds of the Ravenscrag Formation.

The usefulness of many of the water-bearing units in the region is limited by high concentrations of total dissolved solids. Concentrations increase with depth and from west to east.

Levels of iron well above the recommended drinking water standard have been measured in water of the Estevan Valley aquifer.

2. Influence of Coal Mining and Preparation on Ground Water

The impact of coal mining and preparation on the distribution and quality of ground water in the mine areas was examined for the pre-mining, mining and post-mining stages.

Pre-mining Impacts

Pre-mining Drilling and Exploration

1. Exploratory drilling and mine plan drilling may perforate both shallow and deep ground-water systems and increase rates of ground-water mixing and migration.
2. The extent and severity of the impact of exploration activity over large areas in Western Canada are not known.

Mine Site Preparation

1. Mine site preparation includes deforestation and the construction of roadways and coal-processing facilities.
2. Local and intermediate ground-water flow systems in Region 1 may change in both quantity and direction of flow as a result of the influence of deforestation on recharge.
3. The diversion of rivers and streams away from mine sites, particularly in Region 1, will alter local ground-water flow patterns.

4. Construction of roadways and coal processing facilities increases the potential for erosion, particularly in Region 1. Sediments entering surface waters may stress aquatic life and decrease aesthetic value but should have little impact on ground-water quality.

Impacts During Mining

The mining of coal can influence the quantity and distribution of ground water as follows:

- (a) Overburden removal and coal extraction result in the interception of natural ground-water flow and the release of ground water from storage. These disruptions will be more significant in Regions 2 and 3 where mining operations use extensive land areas to extract coal from thin, generally flat-lying and near surface seams.
- (b) Mine dewatering can result in additional ground-water flow to the mine from nearby reservoirs and streams. In many parts of Regions 2 and 3 the coal seams are major sources of domestic water, and dewatering of these seams would result in a loss or reduction in supply. Dewatering operations of mines in Region 1 are generally not seen as deleterious.
- (c) The mining and preparation of coal requires the withdrawal of large quantities of fresh water from surface or ground water. Water withdrawals per tonne of coal produced are greatest in Region 1 where all coal is wet-processed. The majority of mines currently operating in the study area rely primarily on surface sources for water supplies, and it is unlikely that ground-water resources will be significantly affected.

Ground-water quality can be influenced during mining as follows:

- (a) Wastewaters from selected coal facilities in the study area generally satisfy water quality guidelines, but future increases in wastewater production may result in contamination.

- (b) The quality of local ground-water systems can be influenced by the seepage of contaminated preparation plant process water from unlined tailings lagoons and by the seepage and uncontrolled runoff from plant site areas, coal storage piles and coarse refuse piles. There are 12 preparation plants in the study area, all of which are in Region 1.
- (c) At all mines and preparation plants in the study area there is the possibility of surface and ground-water contamination due to leakage from ancillary facilities such as settling ponds, coal storage piles and equipment maintenance sites.
- (d) The degradation of ground-water quality may occur due to the mixing of ground-water zones during the dewatering/mining cycle and seepage of poor quality water from one stratum into another.

Post-Mining Impacts

Mine site reclamation and abandonment can affect ground water as follows:

- (a) Although little is known about post-mining ground-water flow in reclaimed mine areas in Region 1, it is generally anticipated that mine spoils will be more permeable than the pre-mining overburden.
- (b) Extensive strip mining operations in Regions 2 and 3 are most likely to result in significant disturbance of local ground-water flow systems. Therefore, ground-water supplies that existed in the pre-mining system but have been removed or interrupted to access and mine a coal seam are virtually irreplaceable because of limited recharge.
- (c) Where underground mining has taken place the opposite may be true. Abandoned underground mine shafts near Lethbridge in Region 2 have become high-yielding wells.

It is difficult to assess post-mining water quality effects in Regions 2 and 3 because the background water quality is often near the

borderline of potability. Little is known about background water quality in Region 1.

The primary impact on ground water in reclaimed mine areas in Regions 2 and 3 is an increase in the concentration of total dissolved solids relative to undisturbed areas. The lateral migration of degraded water into unmined aquifers has been observed at a mine site in the central part of Region 2.

The development of post-mining acid drainage at mine sites in the study area will be neutralized by carbonate-rich surface deposits and waters.

The long-term effects of coal mining on ground-water quality are not known, but experience from the United States suggests that more serious deterioration may occur many years after the cessation of mining.

Part A

Water Use: Current and Forecast



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Introduction

The following paper derives estimates of water quantity requirements by the coal industry in Western Canada for the year 1990. The derivations are based on the best available information on current coal production, associated water requirements and on projected growth of the coal industry to the year 1990. Initially, forecasts of coal production to the year 2000 were undertaken but, given current uncertainties in both domestic and export markets, it became evident that realistic forecasts beyond the year 1990 could not be made.

The nature and significance of the coal industry in Canada and its attendant demands on water resources are reviewed and the environmental concerns, which were the impetus for the project, and the background and objectives of this study are outlined in the sections which follow.

COAL INDUSTRY IN CANADA

Coal is an important Canadian resource both in its ability to meet primary energy demands and as a contributor to regional and national economic growth and development (Energy, Mines and Resources Canada, 1982). Coal has assumed an increasingly important domestic role as an alternative to oil and also as an international energy commodity (Energy, Mines and Resources Canada, 1980). This role has developed in response to the National Energy Program (NEP) instituted by the federal government in 1980 with the objective of reducing Canadian reliance on imported oil with alternative domestic energy sources. Potential world energy shortages owing to possible shortfalls in world oil supply (Energy, Mines and Resources Canada, 1980) have placed additional pressure on the ability of the coal industry to provide Canada with a further measure of energy security both directly, through expansion, and indirectly through the advancement of technologies for the conversion of coal into synthetic liquid fuels and gas.

Current knowledge of Canada's coal resources indicates that there is approximately 63 578 megatonnes (Mt) of measured and indicated coal resources, and of this amount, about 8500 Mt can be considered for mining using current technology and economics (Bielenstein *et al.*, 1979; Romaniuk and Naidu, 1984). Estimated mineable and recoverable coal reserves in Canada are listed in Table 1.

Table 1. Coal Reserves in Canada, by Rank, 1982*

Rank and province	Coal in mineable seams† (tonnes x 10 ⁶)	Recoverable coal‡ (tonnes x 10 ⁶)	Recoverable coal heating value (joules x 10 ⁶)
Lignite			
Saskatchewan	2121	1697	23 800
British Columbia	<u>739</u>	<u>566</u>	<u>6 800</u>
	2860	2263	30 600
Subbituminous			
Alberta	1314	918	17 150
Bituminous			
Nova Scotia	812	445	12 050
New Brunswick	19.4	17.9	500
Alberta	945	526	12 500
British Columbia	<u>2537</u>	<u>2098</u>	<u>52 400</u>
	4313.4	3086.9	77 450
Total, all ranks	8487.4	6267.9	125 200
Bituminous metallurgical (included in bituminous above)			
Nova Scotia	243	133	
Alberta	604	254	
British Columbia	<u>2201</u>	<u>1643</u>	
	3048	2030	

* Coal deposits with less than 2 Mt recoverable coal have been excluded from this table.

† Coal in mineable seams is defined as the part of measured and indicated resources of immediate interest that can be considered for mining using current technology and economics, before there is an allowance for mining losses.

‡ Recoverable coal is defined as the part of "coal in mineable seams" that would be recoverable as run-of-mine or raw coal, making allowances for mining losses.

Source: Romaniuk and Naidu (1984).

Table 2. Coal Production for Western Canada, 1983 (tonnes)

Province	Thermal		Metallurgical		Provincial totals	Percent
	Surface	Underground	Surface	Underground		
Saskatchewan*	7 650 000	-	-	-	7 650 000	17.35
Alberta†	18 375 616	116 694	5 402 447	744 836	24 639 593	55.89
British Columbia‡	2 200 000	-	8 854 000	746 000 §	11 800 000	26.76
Total	28 225 616	116 694	14 256 447	1 490 836	44 089 593	100
Percent total	64.02	0.26	32.34	3.38		

* Data from Aylsworth (1984).

† Data from Alberta Energy Resources Conservation Board (1984).

‡ Data from P.J. Paine, IPB, EPS, pers. comm., 1985.

§ Estimated.

Total surface = 42 482 063 t = 96.35%

Total underground = 1 607 530 t = 3.65%

In 1983, coal production in Canada reached a record 44.25 million tonnes. Although the current world recession has resulted in short-term problems for the coal industry, particularly the export sector, its future remains optimistic. Recent estimates for the year 2000 have predicted a dramatic increase in total annual production of between 100 and 120 million tonnes. The principal markets for Canadian coal are currently about 65% for electrical energy production (i.e., thermal coal) and 33% for the production of coke used in steel-making (i.e., metallurgical coal). The remaining 2% is consumed by industrial and commercial users (Energy, Mines and Resources Canada, 1983). Table 2 summarizes thermal and metallurgical coal production in Western Canada for 1983.

WATER RESOURCES AND THE COAL INDUSTRY

Water plays an important role in the mining and preparation of coal. The major uses of water are for coal preparation, coal transportation, equipment maintenance, dust suppression, and sanitation. Although it is not currently practised, irrigation of reclaimed mined lands may become an additional future water use. The amount of water required depends primarily on the form of coal extraction, either surface or underground, and the nature and degree of preparation required.

Surface mining operations in Western Canada (British Columbia, Alberta and Saskatchewan) presently account for approximately 96.35% of thermal and metallurgical coal production, and underground mining operations account for the remaining 3.65% (Aylsworth, 1984; Energy Resources Conservation Board, 1984; P.J. Paine, Industrial Programs Branch (IPB), Environmental Protection Service (EPS), pers. comm., 1985). It is expected that coal production from surface mining operations will continue to dominate total coal production to the year 2000.

The two general surface mining methods, open pit and strip mining, require water primarily for dust suppression, sanitary use and equipment maintenance.

Underground mining utilizes three basic techniques: room-and-pillar, longwall and hydraulic (Paine and Blakeman, 1983). During 1983 there were three major underground mining operations in Western Canada. Smoky River Coals Limited uses the room-and-pillar method of underground mining as part of its McIntyre Mine operations near Grande Cache, Alberta. Luscar Sterco Limited also used the room-and-pillar method at its Coal Valley Mine Silkstone Pit near Edson, Alberta, until it was shut down in June 1983. Westar Mining Limited's Michel Mine near Sparwood, British Columbia, is the only underground mine in Canada to use hydraulic mining. This method requires significant amounts of water under high pressure to cut, break, load and transport coal from the working face to the mine mouth (Paine and Blakeman, 1983). Both hydraulic and room-and-pillar underground mining methods require water for sanitary use and equipment maintenance.

In 1983, approximately 57% of the thermal and metallurgical coal production in Canada was subjected to some form of preparation or cleaning to remove inorganic sulphur and ash-forming mineral matter. All preparation plants in Western Canada rely on physical cleaning processes. Most Western Canadian coals used for metallurgical purposes must be processed to remove ash, thereby requiring significant amounts of water in physical cleaning operations such as wet screening and concentration by separation in flotation cells and heavy media vessels. For thermal requirements, lignite and low sulphur subbituminous coals are generally dry-processed by crushing and screening. Thus, no water is required for the cleaning process.

In the future, reclamation and environmental restoration of lands altered by surface coal mining activities may require significant amounts of water for irrigation of revegetated areas.

The development and implementation of new coal liquefaction and/or gasification and transportation technologies, particularly coal-water slurry pipelines, constitute an additional and potentially significant water use by the coal industry.

WATER-RELATED ENVIRONMENTAL AND ECONOMIC CONCERNS OF COAL INDUSTRY EXPANSION

The water needs associated with current and forecast coal mining and preparation activities and the implementation of coal conversion and transportation technologies in Western Canada have major environmental and economic implications. Major increases in water quantity requirements by the coal industry may result in the environmental disturbance of both surface and ground-water regimes. Some possible disturbances are

- (1) Relocation of water drainage systems from large surface mining operations
- (2) Aquifer dewatering in areas of low precipitation which may lead to user conflicts and stresses on water demands where ground water is the major source
- (3) Extensive dewatering to provide access to coal seams and discharge of potentially contaminated ground water to surface waters
- (4) Release of large volumes of contaminated coal wastewaters
- (5) Deforestation of mine sites which may lead to increased runoff, soil erosion and an increase in suspended solids in surface waters (Paine and Blakeman, 1983; see Part B of this report).

These concerns are being addressed by the National Coal Wastewater Program and in part by this study. The National Coal Wastewater Program was undertaken in 1982 by the Environmental Protection Service of Environment Canada to determine qualitative aspects of coal wastewater discharges from mines, preparation plants and bulk transfer/storage terminals (Paine and Blakeman, 1983). A limited but representative number of Canadian coal facilities were selected, and a sampling program was undertaken to characterize quantitatively and qualitatively coal wastewaters with respect to trace elements, inorganic compounds and organic compounds. The sampling and subsequent analyses revealed that at 1982 coal production rates, wastewaters from coal mining and preparation facilities generally satisfied water quality guidelines. The study suggests a number of recommendations as preventive measures against possible environmental contamination from potential increases in wastewater production as a result of future expansion in the coal industry. These include ongoing programs to monitor coal wastewater and settling pond sediments for trace elements and organic

compounds as well as the quality and quantity of ground water in areas where it is a major source of supply for domestic consumption (Paine and Blakeman, 1983).

The economic implications of increased water demands of an expanding coal industry are complex and require careful consideration from all levels of government. Water requirements for future coal development must be assessed alongside the requirements of other sectors of the economy including agriculture, thermal power generation, municipal and rural domestic water supply, manufacturing, hydrocarbon extraction and the petrochemical industry. Water is also an essential requirement for other water-related resources such as recreation, fish and wildlife.

Sustainable economic development depends on water resources planning and management, particularly in Western Canada where water availability varies widely in time and place. Increasingly, the emphasis in water demand management is not to make more water available to satisfy continued growth but to regulate the growth in water demand through achieving greater efficiency in use. The key to this new initiative is conservation with the intention of increasing efficiency and reducing waste in a wide range of economic activity. In terms of the coal industry, conservation might include installation and/or improvement of water recycling equipment, cooling towers in thermal plants and improved irrigation scheduling practices as may be required for future land reclamation projects. The need for improved irrigation practices is emphasized by recent estimates in the United States and the Prairie Provinces of Canada that point to irrigation as a major consumer of water (Prairie Provinces Water Board, unpub. rep., 1984; Hess, 1986). Thermal power plants are often located at or near a coal mine, and although large withdrawals of water are required, primarily for cooling, the rate of consumption is low. This may preclude the location of a thermal plant in areas of wide water supply variation.

An essential input to water planning and management strategies is the assessment of water demands for all sectors based on current and forecast expansion and water requirements for the respective sectors. This report provides such an assessment for the coal industry in Western Canada.

Although water use by the coal industry is on the whole relatively minor, particularly in comparison with agriculture, coal mining may be a relatively high consumer in localized areas.

PROJECT BACKGROUND

The following study was prepared as part of a project initiated by the Environmental Protection Service of Environment Canada to develop environmental protection criteria and/or technologies to ensure that ground-water systems in Western Canada will not be adversely affected by new or expanding coal mining and preparation facilities. The project was divided into two separate studies, which make up Parts A and B of this report.

The purpose of this study is to assess water demands for present and planned coal mining and preparation activities in Western Canada. Its primary objective is to forecast minimum, maximum and most probable water quantity requirements of the coal industry for the year 1990. The forecasts are based on estimates of the following:

- (1) Coal demand by type (thermal or metallurgical) and by location (physiographic province)
- (2) Current water requirements for coal mining and preparation by coal type
- (3) Water requirements for new coal technologies including coal conversion, advanced coal preparation, flue gas desulphurization and coal slurry pipelines based on the likelihood of implementation of these technologies by the year 1990.

The future water requirements of the coal industry are also assessed in relation to the probable demands that would be generated by other sectors of the economy including agriculture, thermal power generation, municipal and rural domestic, manufacturing and mineral extraction.

STUDY AREA

This study focusses exclusively on coal mining in Western Canada. Although eight provinces contain coal deposits, by far the largest deposits

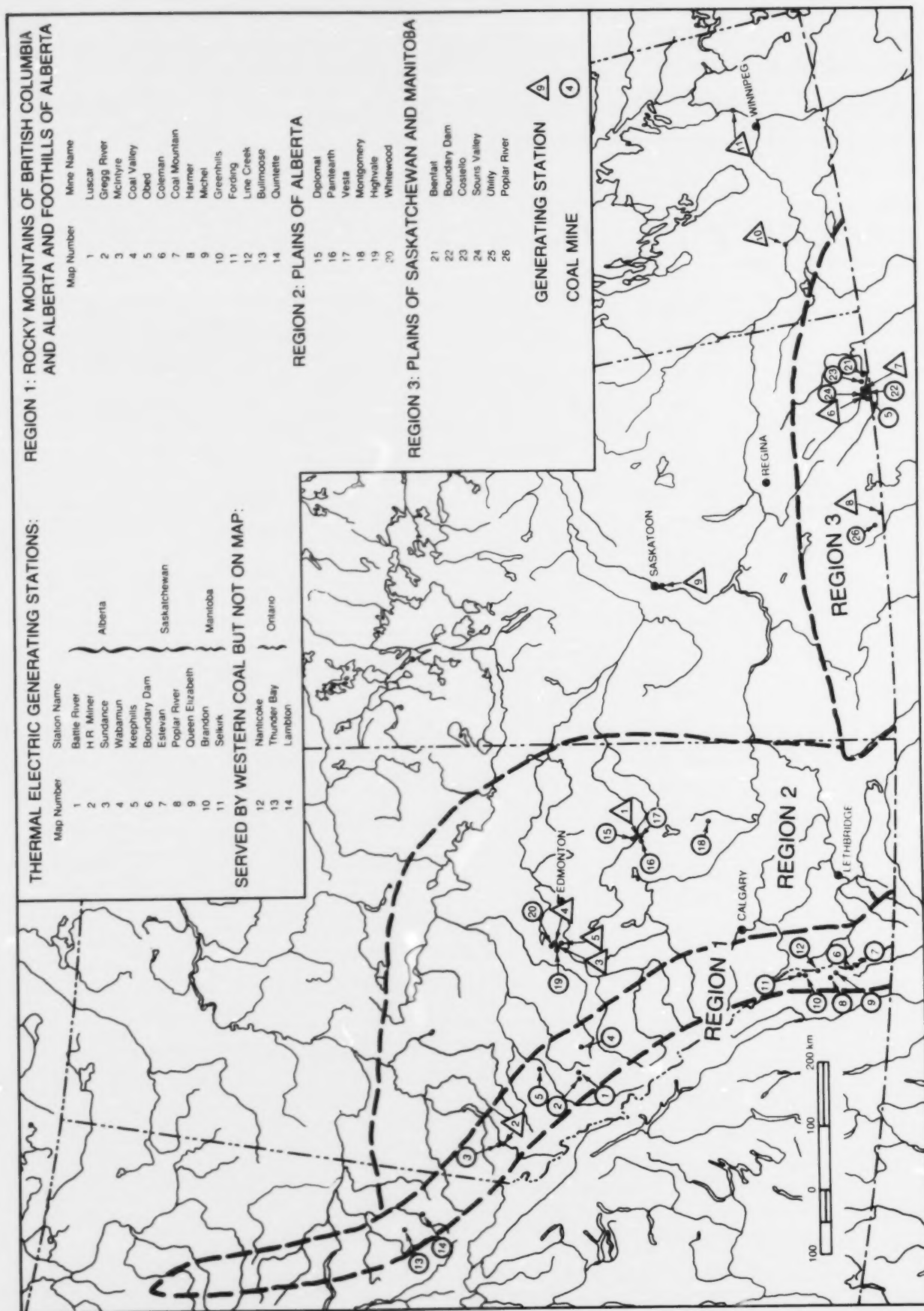


Figure 1. Coal mining water use regions, coal mines and thermal electric generating stations.

are found in British Columbia, Alberta and Saskatchewan. In terms of measured resources irrespective of rank, 90% of coal in mineable seams is located in the three western provinces (Romaniuk and Naidu, 1984).

On the basis of coal rank, coal age and physiography the study area was divided into three distinct regions:

- (1) The Rocky Mountains of eastern British Columbia and the mountains and Foothills of Alberta (upper Jurassic to lower Cretaceous bituminous coals)
- (2) The Plains of Alberta (upper Cretaceous to lower Tertiary subbituminous coals)
- (3) The Plains of Saskatchewan and Manitoba (Tertiary lignitic coals).

These regions are delineated in Figure 1.

Coal Mining and Preparation in Western Canada

This chapter provides a detailed review of current coal mining and preparation in the study area. Principal mines and preparation plants are identified and described. Mining and preparation techniques used in the study area are described with particular emphasis on water requirements. Although complete data are often neither readily available nor necessarily representative of total water use, an attempt is made to quantify *water use*¹ on a per mine and preparation plant basis. Estimates of *water withdrawal*² for coal mining and preparation in each of the three coal-processing regions are derived and these estimates are used later in this report to forecast water demands by the coal industry for the year 1990.

COAL MINES AND PRODUCTION

The locations of current (1983) principal coal mines within the three regions defined by this study are shown on Figure 1. Table 3 lists the mines by region and summarizes available information with respect to production, type and rank of coal produced, type of mining, type of preparation and principal destination of the product coal.

Region 1

Subbituminous and bituminous coals occur, respectively, in the Foothills and mountain areas of Alberta and British Columbia (Fig. 1), reflecting the trend of increasing rank with increasing orogenic activity.

¹ Water use refers to the quantity of water required at a facility (mine and/or preparation plant) on a per unit of time or production basis (i.e., per day or cubic metres per tonne) to perform a given function.

² Water withdrawal refers to total intake of fresh water from a surface or ground-water source for use in a particular facility.

Table 3. Coal Mine Operators in Western Canada, 1983/1984

Mine name and location	Principal owner and/or company	Production 1983 (t x 10 ³)	Coal rank	Coal type	Type of mining	Type of preparation	Destination of coal and principal uses
Region 1							
Coal Mountain Mine (formerly Corbin Mine) Corbin, B.C.	Byron Creek Collieries Ltd.	A.S. 1146 R.O.M. 1340 (Est.)	mwb	Thermal	Surface	Wet; prep. plant at mine site	Ontario Hydro (Nanticoke I.G.S.), Hong Kong, U.S.A., Manitoba (Hudsons Bay Smelting), British Columbia (Cominco Smelter)
Hammer Mine, Sparwood, B.C.	Westar Mining Ltd.	A.S. 6400 R.O.M. 5676	lvb to mwb	Metall.	Surface	Wet; prep. plant at Elkview, B.C.	Japan, Mexico, Italy, Brazil, Romania, Sweden, Korea; coke production
Michel Mine, Natal, B.C.	Westar Mining Ltd.		lvb to mwb	Metall.	Underground	Wet; prep. plant at Elkview, B.C.	Japan (coke production)
Greenhills Mine, Elkford, B.C.	Westar Mining Ltd.		hvb and mwb	Thermal and metall.	Surface	Metall.-wet thermal-dry prep. plant at mine site	Metall. to South Korea, Japan, Taiwan, Hong Kong, and Europe for coke production. Thermal to Denmark, Pacific Rim, and South Korea
Fording Mine, Elkford, B.C.	Fording Coal Ltd.	A.S. 2860 R.O.M. 4866	Primarily lvb but also mwb and hvb	Metall.	Surface	Wet; prep. plant at mine site	Japan, Pacific Rim countries, South America and Europe; coke production

* Not indicated in Figure 1.

Note: Production figures are clean coal or as shipped (A.S.); whenever possible run-of-mine (R.O.M.) data are provided or estimated (Est.).

mwb - Median volatile bituminous.

lvb - Low volatile bituminous.

hvb - High volatile bituminous.

sub - Subbituminous.

lig - Lignite.

T.G.S. - Thermal generating station.

Sources: Aylsworth (1984); Romaniuk and Maidu (1984); Environment Canada (unpub. rep., 1984a); Energy Resources Conservation Board (1984).

Table 3. Continued

Mine name and location	Principal owner and/or company	Production 1983 (t x 10 ³)	Coal rank	Coal type	Type of mining	Type of preparation	Destination of coal and principal uses
Line Creek Mine, Elkford, B.C.	Crows Nest Resources Ltd.	A.S. 1800 (Est. 936 thermal, 864 metall.) R.O.M. 2040 (Est. 959 thermal; 1081 metall.)	mvb and 1vb	Thermal and metall.	Surface	Metall.-wet thermal-wet & dry separate prep. plants at mine site	Metall. to Japan (coke production); thermal to Korea (power generation)
Bullmoose Mine, Tumbler Ridge, B.C.	Teck Corporation	A.S. 240 (metall. only 1983); R.O.M. 350 (Est.)	mvb	Thermal and metall.	Surface	Metall.-wet Thermal-wet; prep. plant at mine site	Metall. to Japan (coke production); thermal unknown but assumed for export to Pacific Rim
Quintette Mine, Tumbler Ridge, B.C.	Denison Mines Ltd.	A.S. 100 (thermal only during 1983) R.O.M. 120 (Est.)	mvb	Thermal and metall.	Surface	Metall.-wet thermal-wet; prep. plant 13 km from mine site	Metall. to Japan (coke production); thermal to Pacific Rim and Europe
Coal Reclamation Project (Coleman Mine), Coleman, Alta.	Coleman Collieries Ltd.	A.S. 186 R.O.M. 675 (operations completed Oct. 1983)	mvb	Thermal	Reclamation of old mine waste dumps	Wet prep. plant at mine site	Exported
McIntyre Mine, Grande Cache, Alta.	Smoky River Coals Ltd.	A.S. 1600 R.O.M. Surface 1480 metall. 80 thermal Under-ground 745 thermal 2305	1vb	Thermal and metall.	Surface and underground	Metall.-wet thermal-wet & dry prep. plant at mine site	Metall. to Japan, Pacific Rim, and southern Ontario (Dofasco and Stelco) for coke production; thermal to mine mouth power plant (H.R. Milner I.G.S.)
Luscar Mine (formerly Cardinal River Mine), Hinton, Alta.	Cardinal River Coals Ltd.	A.S. 2300 R.O.M. 2856	mvb	Metall.	Surface	Wet prep. plant at mine site	Metall. to Japan (coke production)

Table 3. Continued

Mine name and location	Principal owner and/or company	Production 1983 (t x 10 ³)	Coal rank	Coal type	Type of mining	Type of preparation	Destination of coal and principal uses
Gregg River Mine, Hinton, Alta.	Gregg River Resources Ltd.	A.S. 675 (metall. only; thermal coal stock piled without prep.) R.O.M. 1329 (263 thermal, 1066 metall.)	mwb	Thermal and metall.	Surface	Metall.-wet thermal-wet; prep. plant at mine site	Metall. Japan (coke production); thermal exported
Coal Valley Mine, Edson Alta.	Luscar Sterco (1977) Ltd.	A.S. 2100 R.O.M. Surface 3568 Underground 116 3684	hvb	Thermal	Surface and underground (closed June 1983)	Wet; prep. plant at mine site	Principally to Ontario Hydro (Lambton and Nanticoke T.G.S.) and also to Japan, West Germany, Pacific Rim and for industrial use in Manitoba (Flin Flon)
Obed Marsh Mine, Hinton Alta.	Union Oil Company of Canada	Operations commenced 1984	hvb	Thermal	Surface	Wet; prep. plant at mine site	Pacific Rim and Europe for power generation
<u>Region 2</u>							
Highvale Mine, Seba Beach, Alta.	TransAlta Utilities Corp.	A.S. 9597	sub	Thermal	Surface	Initial crushing at mine; final size reduction by crushing and dry screening at power plant	Primarily for mine mouth thermal power generation (Sundance T.G.S.); also shipped to Keephills T.G.S. near Edmonton
Whitewood Mine, Wabamun, Alta.	TransAlta Utilities Corp.	A.S. 1994	sub	Thermal	Surface	Initial crushing at mine; final size reduction by crushing and dry screening at power plant	Mine mouth thermal power generation (Wabamun T.G.S.)

Table 3. Continued

Mine name and location	Principal owner and/or company	Production 1983 (t x 10 ³)	Coal rank	Coal type	Type of mining	Type of preparation	Destination of coal and principal uses
Diplomat Mine, Forestburg, Alta.	Forestburg Collieries Ltd.	A.S. 344	sub	Thermal	Surface	Initial crushing at mine; final size reduction by crushing and dry screening at power plant	Primarily for mine mouth thermal power generation (Battle River T.G.S.); some shipped to Queen Elizabeth T.G.S. (Saskatoon, Sask.); some shipped to industrial and domestic markets
Paintearth Mine, Forestburg, Alta.	Forestburg Collieries Ltd.	A.S. 1272	sub	Thermal	Surface	Initial crushing at mine; final size reduction by crushing and dry screening at power plant	Thermal power generation (Battle River T.G.S.)
Vesta Mine, Halkirk, Alta.	Manalta Coal Ltd.	A.S. 1129	sub	Thermal	Surface	Initial crushing at mine; final size reduction by crushing and dry screening at power plant	Mine mouth thermal power generation (Battle River T.G.S.)
Montgomery Mine (formerly Roselyn Mine), Sheerness-Hanna Alta.	Manalta Coal Ltd.	A.S. 94	sub	Thermal	Surface	Some crushing and dry screening at mine	Local domestic uses and thermal power generation; also industrial use and some shipped to Queen Elizabeth T.G.S. (Saskatoon, Sask.)
Dodds; Pyramid; Egg Lake; North Point; Picardville; Sissons; Pinter-Warburg*	Various	Totals for all 7 small mines; A.S. 35	sub and lig	Thermal	Surface and underground (Pyramid Mine)	Some crushing and dry screening at mines	Primarily for residential heating with some industrial use

Table 3. Continued

Mine name and location	Principal owner and/or company	Production 1983 (t x 10 ³)	Coal rank	Coal type	Type of mining	Type of preparation	Destination of coal and principal uses
Region 3							
Poplar River Mine (formerly Coronach Mine), Coronach, Sask.	Saskatchewan Power Corp.	A.S. 2334	lig	Thermal	Surface	Initial size reduction at mine; balance completed at power plant by crushing and dry screening	Mine mouth thermal power generation (Poplar River T.G.S.)
Boundary Dam Mine, Estevan, Sask.	Manitoba and Saskatchewan Coal Company Ltd.	A.S. 1202	lig	Thermal	Surface	Initial size reduction at mine; balance completed at power plant by crushing and dry screening	Mine mouth thermal power generation (Boundary Dam T.G.S.); some shipped to Brandon, Man. T.G.S.
Costello Mine (formerly Klinax Mine), Estevan, Sask.	Manalta Coal Ltd.	A.S. 468	lig	Thermal	Surface	Crushing and dry screening at mine	Thermal power generation (Boundary Dam T.G.S.) and local residential heating; some shipped for industrial use to Sask., Man., and Ont.
Souris Valley Mine, Estevan, Sask.	Saskatchewan Power Corp.	A.S. 144 (mine was closed during summer of 1983)	lig	Thermal	Surface	Initial size reduction at mine; balance completed at power plant by crushing and dry screening	Thermal power generation (Boundary Dam T.G.S.)

Table 3. Concluded

Mine name and location	Principal owner and/or company	Production 1983 (t x 10 ³)	Coal rank	Coal type	Type of mining	Type of preparation	Destination of coal and principal uses
Utility Mine, Estevan, Sask.	Saskatchewan Power Corp.	A.S. 2402	lig	Thermal	Surface	Initial size reduction at mine; balance completed at power plant by crushing and dry screening	Thermal power generation (Boundary Dam T.G.S.); some shipped to Selkirk, Man. T.G.S.
Bienfait Mine, Bienfait, Sask.	Bienfait Coal Company Ltd.	A.S. 1210	lig	Thermal	Surface	Crushing and dry screening at mine	Thermal power generation (Boundary Dam T.G.S.); some shipped to Brandon, Man. T.G.S. and Thunder Bay, Ont. T.G.S.; lignitic char produced for barbeque briquettes
Turtle Mountain Mine, Wassewa, Man.*		A.S. 5	lig	Thermal	Surface	None	Local industrial use

The Foothills coals are primarily high volatile bituminous and are mainly suitable as high grade, low sulphur thermal coals. The mountain regions contain mostly low and medium volatile bituminous coals suitable for metallurgical coke production.

Metallurgical Coals of Mountain Areas

Approximately 19.6 million tonnes of metallurgical grade coal was produced from mines in the mountain regions in 1983. Varying proportions of oxidized metallurgical coal are mined in the region and marketed as thermal coal. Although underground production is used on a reduced scale at the McIntyre and Coal Valley mines using the room-and-pillar method and on a large scale at the Michel Mine using the hydraulic method, the bulk of coal output (approximately 93%) is obtained by surface mining methods. All metallurgical coal, including the oxidized portions, requires wet preparation.

Thermal Coals of Mountain Areas

Certain mines in the mountain areas of Region 1 produce a medium volatile bituminous coal which is used for thermal electric power generation. Approximately 0.7 million tonnes was produced by surface mining methods. Only a minimum of beneficiation, primarily for ash and moisture reduction, is required to produce a thermal coal for export or for supply to Ontario (Butcher, 1982).

Thermal Coals of the Foothills

In 1983 approximately 7.4 million tonnes of high volatile bituminous coal was produced from mines in the Foothills using conventional draglines, trucks and shovels. Extensive preparation is required to reduce the ash content of these coals which are primarily for the export market.

Region 2

Coals from the Plains region of Alberta (Fig. 1) are primarily lower rank subbituminous coals suitable for thermal electric power generation.

Table 4. Thermal and Metallurgical Coal Production in Western Canada, 1983

Region	Coal type	Approximate run-of-mine production (Mt)	Coal rank	Mining methods	Preparation required	Principal use
Region 1	Thermal	0.7	mwb	Surface	Yes; minimum	Thermal electric power generation
	Thermal	7.4	hvb	Surface and underground	Yes	Thermal electric power generation
	Metallurgical	19.6	lvb and mwb	Surface and underground	Yes	Metallurgical coke production
Region 2	Thermal	16.1	sub	Surface	No	Thermal electric power generation
Region 3	Thermal	8.2	lig	Surface	No	Thermal electric power generation
Total		52.0				

mwb - Medium volatile bituminous. Sub - Subbituminous.

hvb - High volatile bituminous. lig - Lignite.

lvb - Low volatile bituminous.

Sources: Energy Resources Conservation Board (1984); Environment Canada (unpub. rep., 1984a).

domestic heating, industrial application and coal conversion processes such as gasification and liquefaction. Approximately 16.1 million tonnes was produced from surface mines in this region in 1983. Almost all of the coal produced was used without preparation at mine mouth thermal electric power generating stations.

Region 3

The Plains region of Saskatchewan and Manitoba (Fig. 1) yields lignite coals which are mainly marketed as mined to thermal power plants in Saskatchewan and Ontario (Bielenstein *et al.*, 1979). Approximately 8.2 million tonnes of coal was produced in 1983 by surface mining methods. Similar to subbituminous coals, the lignite coals are used without preparation at mine mouth thermal electric power generating stations.

Summary

Table 4 provides a summary of thermal and metallurgical coal production in the coal-producing regions of Western Canada.

COAL MINING METHODS AND ASSOCIATED WATER USE

Coal producers in Western Canada currently use both surface and underground mining methods, with surface mining accounting for approximately 98% of the total coal production within the three regions. In the following sections these methods are described and their associated water uses identified.

Water use data are available in the form of questionnaires from individual coal mining companies. Data from the questionnaires can be used to estimate the total water requirement at a facility but cannot be used to estimate water consumption. Less than half of the operating coal mines responded to the 1981 survey; information derived from the 1981 survey is referenced as: Statistics Canada/Environment Canada (unpub. data, 1982). The questionnaire data are collected under provisions of the Statistics Act which prohibits the release of specific survey data or information.

Surface Mining

Two general surface mining methods, open pit and strip, are used to extract coal from near surface deposits. Open pit mining is used almost exclusively in the mountain and Foothills region where coal is generally extracted from steeply dipping seams. Strip mining is best suited to extract coal from flat-lying or gently dipping seams found in the Plains regions. Approximately 96% of the current coal production in the study area is surface mined, and of that, 55% is strip-mined and 45% mined from open pits.

Open Pit Mining

Open pit mining is best characterized by the progressive excavation of steep-sided benches and the creation of one or more deep, irregularly shaped pits from which soil and rock overburden are removed and coal is exposed and extracted. The equipment normally used for overburden removal and mining consists of stripping and loading power shovels, bulldozers, front end loaders and large-capacity haulage trucks.

Water is not used in the mining operation itself but is required for sanitary use, dust suppression and equipment maintenance. Estimates of sanitary water use are based on a design figure of 320 L/day per person. Little, if any, information exists regarding the use of water alone or in combination with other agents for dust suppression at mines in the study area. The frequency of application of water alone would depend primarily upon local climatic conditions. According to Techman Engineering Ltd. (1982), daily application at a rate of at least 1.0 L/m^2 would be required where the air temperature was above 0°C . The use of other agents would decrease the amount of water required as well as the frequency of application.

The quantity of water required for equipment maintenance varies with each operation. Data from open pit mines in the East Kootenay area indicate that approximately 4% of the total annual water intake is required for equipment maintenance.

Open pit mining results in significant land surface disturbance. Reclamation of worked out pits and waste disposal sites may take many years to complete, and in the future, revegetated areas may require supplemental water if annual precipitation is low. Ample moisture at planting and during establishment is critical for revegetation. This requirement may increase the demand for water use and may become important in those areas with low precipitation.

Strip Mining

Strip mining operations are characterized by the removal of soil and rock overburden to varying depths to expose and extract flat-lying or gently dipping coal seams. Electrically powered draglines are most commonly used to strip the overburden and expose the coal. Power shovels or front end loaders are normally used to load the broken coal into haulage trucks.

Water is not used in the mining operation itself but is required for sanitary use, dust suppression and equipment maintenance. Water requirements for sanitary use and equipment maintenance are similar to those described above for open pit mines. Dust suppression water requirements are much greater than for open pit mines for two reasons: (1) strip mining activities occur within drier climatic regions and (2) haulage distances and therefore surface areas are much greater. Dust suppression water use at two strip mines in Saskatchewan has been estimated at 15 000 and 45 500 m³ annually (Statistics Canada/Environment Canada, unpub. data, 1982; P.J. Paine, IPB, EPS, pers. comm., 1984). Both figures represent approximately 90% of the total annual water intake at these mines.

During strip mining operations water collects in the mine as a result of ground-water seepage, surface runoff and direct precipitation. Under provisions of the Alberta Clean Water Act and the Water Resources Act and the Saskatchewan Mineral Resources Act, these mine wastewaters may not be discharged into local drainage systems without prior treatment. In practice, any water entering the mine is collected and pumped to retention ponds or other treatment facilities. Although data are not available, significant

quantities of water are probably lost due to evaporation from the surfaces of retention ponds. Seepage losses may also be significant.

The amount of land surface disturbed as a result of strip mining is greater than for any other mining method. Reclamation of disturbed lands involves revegetation over a large area and potential disturbance of near surface aquifers. Although irrigation has not been practised to date, it may in the future place demands on ground-water supply in the semi-arid regions of southern Saskatchewan and southeastern Alberta.

Underground Mining

Underground mining utilizes three basic techniques: room-and-pillar, longwall and hydraulic. There are only three underground mines in the study area from which 3.65% of coal production in 1983 was mined. Approximately one half of the coal produced from the McIntyre Mine near Grande Cache, Alberta, was obtained using room-and-pillar mining; the longwall method had been used initially but proved unsuccessful. The Michel Mine at Sparwood, British Columbia, also used the room-and-pillar method, but most of the coal is now obtained by hydraulic mining. The room-and-pillar method had been used to mine a small amount of coal from the Silkstone Pit of the Coal Valley Mine near Edson, Alberta, until it was shut down in June 1983.

Room-and-Pillar Mining

This method is characterized by the extraction of coal contained within alternating regularly spaced square or rectangular blocks within a coal seam. Openings perpendicular to each other are made in the seam from which coal is then extracted, generally with mining machines, and removed using conveyor belt systems.

Water is not used in this method of mining but is required for sanitary use, equipment maintenance and, in certain cases, for dust suppression. Mines in the study area using the room-and-pillar method store or dispose of a negligible amount of waste material on the surface.

Hydraulic Mining

Hydraulic mining uses water under high pressure (141 kg/cm², or 2000 psi) to cut, break, load and transport coal from the working face to the mine mouth. Water from a high volume, high pressure pump near the mine entrance is fed to a monitor at the mine face. Water directed from the monitor nozzle cuts coal from the roof and face of the seam. The resultant coal-water slurry flows away from the face and is pumped to the mine mouth. After dewatering, the coal is trucked to a preparation plant and the recovered water is recycled to the monitor.

This type of mining is designed to operate on a closed loop system with 100% water recycle. However, water is lost from the system due to seepage into fractures within the coal seam and evaporation and through losses incurred in the dewatering process. The flow rate of the Michel Mine hydraulic operation is approximately 11.4 m³/min with a 5% to 10% makeup water requirement (P.J. Paine, IPB, EPS, pers. comm., 1984). Water is also required for sanitary use and equipment maintenance as described in previous sections.

The volume of solid waste generated by the Michel Mine is negligible with little or no surface disposal.

COAL PREPARATION AND WATER USE

The main purpose of coal preparation (also referred to as beneficiation, cleaning or washing) is to upgrade a coal by removing inorganic sulphur and ash. The nature of the preparation processes and the degree of preparation depend on the ultimate use of the coal.

Within the study area all metallurgical coals and approximately 25% of the thermal coals produced in 1983 were upgraded in wet preparation plants. These plants contain a variety of equipment to crush, size and clean the coal.

The cleaning equipment and processes generally rely upon gravity separation in an aqueous medium to facilitate removal of the heavier specific

gravity waste materials, such as rock particles, clay, and sand from the lighter specific gravity coal.

Approximately 71% of the thermal coal produced in the study area in 1983 was crushed and dry-screened at receiving thermal electric generating stations. Another 7% was crushed and dry-screened at the mine site. Some of the coal may also be pulverized and burned at the power plants as received run-of-mine coal (Blakeman *et al.*, 1982). The current preparation practices in the study area and regional coal preparation data for 1983 are summarized, respectively, in Tables 5 and 6.

In general, coal preparation can be divided into physical (mechanical) and chemical processes. Currently, all preparation plants in the study area rely on physical cleaning. Chemical coal cleaning technologies are not technically or economically feasible at this time (Paine and Blakeman, 1983).

Physical coal cleaning may be divided into wet and dry processes. These processes are described in the following sections, with emphasis on the quantities of water withdrawn and consumed.

Table 5. Coal Preparation Practices in the Study Area, 1983

Preparation	Thermal	Metallurgical	Total
Washed (t)*	7.2 (22)	19.6 (100)	26.8 (52)
Dry preparation at mine (t)	2.1 (7)	-	2.1 (4)
Dry preparation at power plant (t)	23.1 (71)	-	23.1 (44)
Total study area production (t)	32.4	19.6	52.0

*Run-of-mine, tonnes x 10⁶; numbers in parentheses refer to percentage of total.

Table 6. Coal Preparation Practices by Region, 1983

Practices	Region 1	Region 2	Region 3
Total production (10 ⁶ t ROM)	27.674	16.1	8.156
Metallurgical (10 ⁶ t ROM)	19.629	-	-
Thermal (10 ⁶ t ROM)	8.045	16.1	8.156
Estimated percent metallurgical washed	100	-	-
Estimated percent thermal (bit) washed	97	-	-
Estimated percent thermal (sub and lig) dry screened at power plant	-	>99	78
Estimated percent thermal (sub and lig) dry screened at mine	-	<1	22

ROM - Run-of-mine.

bit - bituminous.

sub - subbituminous.

lig - lignite.

Dry Coal Preparation

Dry coal preparation techniques are used in ten preparation plants in the study area and accounted for approximately 48% of total coal production in 1983. Although some initial crushing and in some cases dry screening of subbituminous and lignitic coal is done at the mine, most of the final size reduction is completed at the receiving thermal electric generating stations (refer to Tables 5 and 6).

Dry coal preparation is usually selected when liquid-based separation processes cannot be used because certain coals do not react well to the addition of moisture. Because most of the mine mouth thermal power plants in Western Canada have been designed to burn essentially run-of-mine

coal, the processing employed does not have to "clean" the coal to meet stringent ash requirements (W.B. Blakeman, IPB, EPS, pers. comm., 1984).

In a typical dry preparation plant, run-of-mine coal is reduced in size by rotary breakers and roll crushers and then classified into the desired size ranges using vibratory screens. These processes do not require the use of water.

Wet Coal Preparation

Wet coal preparation techniques are used in 12 preparation plants in the study area and accounted for approximately 52% of the total coal production in 1983 (refer to Tables 5 and 6).

In principle, wet preparation processes involve crushing, screening and specific gravity separation of the coal fragments from impurities in an aqueous medium. The sized and cleaned product is dewatered and thermally-or air-dried prior to shipment. The equipment used at a preparation plant is largely dependent on the nature of the run-of-mine coal and consumer quality requirements for inorganic sulphur and ash. Crushing equipment consists of rotary breakers, roll crushers and hammermills. Although none of this equipment requires process water, some water may be required for dust control. Depending on the size of coal, wet or dry screening may be used to separate the coal into size ranges before introduction to coal cleaning circuits.

If additional cleaning is required coarse coal may be separated from the waste through the use of jigs, heavy media vessels or heavy media cyclones. Jigging involves the stratification of raw coal in water by air pressure pulsations that rearrange the particles according to density; the less dense coal moves to the top of the bed, whereas the more dense impurities settle to the bottom. The two components are collected separately. According to Williams (1981), jigs require the greatest quantities of water in the preparation process. Heavy media vessels use media with specific gravities greater than coal but less than that of the impurities to be removed. A slurry of water and finely ground magnetite is usually employed as the medium. Considerable amounts of water are used in

the separation process (Hutton and Gould, 1982). Heavy media cyclones also use a water and magnetite slurry to separate coal from its impurities but enhance the separation by the use of centrifugal force.

Coal and waste particles in the intermediate and fine size ranges are most commonly separated in hydrocyclones or in froth flotation cells. Hydrocyclones, or water-only cyclones, enhance separation of coal and impurities by centrifugal force but use water instead of a heavy media mixture. Water requirements are high for this type of process (Hutton and Gould, 1982). The froth flotation process takes advantage of the water repelling or hydrophobic properties of coal. As a result of this process, the fine coal particles float in an air-agitated slurry of coal, water and sometimes chemical reagents. As they rise to the surface they are skimmed off in the froth. This process is not a major consumer of water, although makeup water is required to replace that which is lost in the froth removal.

Wet physical coal cleaning processes leave a significant amount of moisture on the coal and subsequent treatment is required to reduce the moisture content to specified levels. Product coal is mechanically dewatered using screens, centrifugal dryers and vacuum filters. Air or thermal drying may follow.

The sieve bend is the most commonly used screening device for preliminary dewatering before the coal passes to the vibratory screens and centrifuges (Hutton and Gould, 1982). Centrifugal dryers are used to dewater coal by spinning in a centrifuge. Vacuum filters are another common dewatering device, particularly for fine-sized coal particles. In this method, solids form a cake on the leaves of a filter which is rotated through a coal-water slurry. The dewatered coal is removed from the filter by blasts of air. Water is used in each of these treatments, but consumption is assumed to be minimal.

A final treatment which may be used to reduce the moisture content of the cleaned coal is thermal drying whereby surface moisture is removed by passing heated air through a moving bed of coal. Thermal dryers are usually fuelled by either coal or natural gas. This moisture is lost to the

atmosphere and represents an amount of water that must be made up elsewhere in the system. Water loss due to evaporation during thermal drying is estimated to be approximately $0.12 \text{ m}^3/\text{t}$ of coal input (Butcher, unpub. rep., 1984). This estimate is based on a reduction of moisture content from about 20% for the coal input to about 8% for the dried product coal.

Wash waters contaminated with fine refuse are generated at various stages during coal preparation. To prepare fine refuse for disposal as tailings and to ensure maximum recirculation of wash water in the preparation plant, it is necessary to separate contaminated wash water from the refuse solids. Refuse is dewatered by using basically the same methods as described for fine coal recovery, namely, centrifugal dewatering and filtration. The most commonly used piece of equipment for clarifying wash water is the gravitational clarifier or thickener, a large circular basin in which solids settle to the bottom. From here they can be removed by scraper blades. Clarified water is removed as overflow and recycled to the preparation plant. Flocculation reagents may be added to the water in the clarifier to assist the settling process. The thickener underflow may be further treated for the removal of coal fines by centrifugal and thermal drying.

The majority of preparation plants within the study area use tailings ponds or settling ponds to clarify coal wastewaters by the sedimentation of fines. Wastewaters include surface runoff, storage pile runoff and preparation plant discharges. Significant quantities of water are lost from these ponds due to surface evaporation and seepage to ground water. Evaporative losses may be estimated using conventional hydrological equations. Seepage losses can also be estimated but with greater difficulty.

Summary

Depending on the physical composition of the raw coal and the market requirements for cleaned coal, individual preparation plants may employ different combinations of the methods and equipment described, and may practise varying degrees of water recirculation. Accordingly, it is not possible, on an industry-wide basis, to equate water usage in terms of volumes consumed to tonnes of coal produced (Blakeman, 1980).

Coal preparation plants may require up to 10.0 m^3 of water per tonne of feed coal (Williams, 1981). If neither water treatment nor recycling are practised, this volume represents a net demand for fresh water. As part of their provincial licensing requirements, however, all coal preparation plants in the study area must provide facilities to recirculate wastewaters. All process water is recycled within the plant itself, or within a closed circuit preparation plant - tailings impoundment system. According to Williams (1981), this results in a decrease in water consumption from 0.09 to $1.5 \text{ m}^3/\text{t}$ of feed coal. This net requirement is independent of the types of preparation processes.

Varying quantities of water are normally lost in the drying stages and with the shipped (product) coal, which commonly has a moisture content in the range of 6% to 9%. Other sources of water loss include seepage and evaporation from the tailings impoundment area. Process water must therefore be augmented with fresh makeup water from local streams or wells (Blakeman, 1980).

Makeup water needs for six coal preparation plants in the United States examined by Hutton and Gould (1982) ranged from 0.04 to $9.1 \text{ m}^3/\text{min}$, with larger and more complex plants usually requiring larger amounts of water than the smaller, less complex plants.

Within the study area there are generally two levels or degrees of preparation required. Thermal coals in the mountain areas of Region 1 generally require a minimum amount of preparation. The metallurgical coals in the mountain areas of Region 1 and the thermal coals in the Foothills areas of Region 1 require extensive preparation to meet stringent ash limits. Thermal coals in Regions 2 and 3 need little or no preparation.

It is not currently possible or within the scope of this study to quantify water use requirements and water losses (i.e., consumption) at each step during the wet preparation of coal. It has been possible, however, to estimate overall water use and to identify where water losses occur.

CURRENT WATER USE IN THE COAL INDUSTRY

Current trends of water use at mines and preparation plants in the study area are reviewed and estimates of total coal mining and preparation water use in each region are presented. Additional water requirements for activities related to the coal industry are not included in the above estimates but are discussed.

Water Use in Region 1

There are three principal coal-producing areas and 14 operating mines in Region 1 (Fig. 1):

- (1) The *Wolverine* area of northeastern British Columbia
- (2) The *Yellowhead* area of west-central Alberta
- (3) The *East Kootenay* area of southeastern British Columbia and southwestern Alberta.

All metallurgical and thermal coals undergo wet preparation at on site plants to satisfy consumer ash requirements. Principal freshwater withdrawals at all mines are for preparation plant process water, mine and preparation plant sanitary use, equipment maintenance and dust suppression. Preparation plant wastewaters are discharged to tailings ponds and clarified water is recirculated to the plant or, under special provincial permits (Alberta), discharged to the receiving environment.

Evaporative and seepage losses from tailings ponds may be significant but are difficult to estimate. The magnitude of these losses depends on several site specific conditions such as surface area and exposure, climate, impoundment design, construction materials and sub-surface soil conditions.

All water withdrawn for sanitary use, equipment maintenance and dust suppression may be regarded as consumed.

Wolverine Area

The Bullmoose and Quintette mines commenced operation in the Wolverine area in late 1983. Both are open pit mines producing metallurgical and thermal coals.

It is estimated that approximately 0.4 m^3 of water is required to produce 1 t of coal at either mine.³ Of this amount, approximately 60% to 70% is consumed due to evaporative loss during thermal drying and moisture retention by the product coal.

Initial water requirements and makeup water supplies are obtained from surface water sources.

Yellowhead Area

There are five producing coal mines in the Yellowhead area of west-central Alberta, namely, the Luscar (formerly Cardinal River Mine), Gregg River, Coal Valley, Obed Marsh (opened in 1984) and McIntyre mines.

Metallurgical coals are mined from open pits at the Luscar, Gregg River and McIntyre mines and from an underground operation at McIntyre Mine. Thermal coals are strip-mined at the Coal Valley and Obed Marsh mines and open pit mined at Coal Valley. The McIntyre Mine markets, as thermal coal, the primary rejects and tailings from the preparation plant. As noted earlier, varying proportions of oxidized metallurgical coal are mined in the area and marketed as thermal coal (e.g. Gregg River).

Within this area water use ranges from 0.33 to $1.85 \text{ m}^3/\text{t}$ of product coal. A large percentage of this amount is consumed due to evaporative loss during thermal drying and moisture retention by the product coal.

Two of the three mines operating in this area in 1981 obtained 94% and 96% of total freshwater intake from surface water sources. The third

³ The derivation of water use coefficients is discussed in Chapter 5 of Part A.

mine obtained 54% of total freshwater intake from ground-water sources and the remaining 46% from surface water sources (Statistics Canada/Environment Canada, unpub. data, 1982).

East Kootenay Area

There are six producing coal mines in the east Kootenay area of southeastern British Columbia, namely, Coal Mountain (formerly Corbin Mine), Harmer, Michel, Greenhills, Fording River and Line Creek mines. The coal reclamation project at the Coleman Mine was completed in October of 1983.

Thermal coals are mined at the Coal Mountain, Greenhills and Line Creek mines and metallurgical coals at the Harmer, Greenhills, Fording River and Michel mines. A medium volatile bituminous thermal coal was produced at the Coleman Mine through the reclamation of old mine waste dumps.

Within this area water use ranges from 0.06 to 0.66 m³/t of product coal. A large percentage of this amount is consumed due to evaporative loss during thermal drying (except for Coal Mountain where thermal driers are not used) and moisture retention by the product coal.

During 1981, two mines operating in this area obtained more than 95% of their total freshwater intakes from surface water sources, whereas two other mines obtained more than 95% from ground-water sources. The recirculation of process water, generally from a holding or settling pond, ranged from 5 to 41 times the total water intake (Statistics Canada/Environment Canada, unpub. data, 1982). One mine did not respond to the 1981 water use survey, and the Greenhills and Line Creek mines were not yet in operation.

Water Use in Region 2

There are two principal coal-producing areas and six operating mines in Region 2 (Fig. 1): the Lake Wabamun area west of Edmonton and the Forestburg/Halkirk area southeast of Edmonton. Thermal coal is strip-mined in the Lake Wabamun area at the Highvale Mine near Seba Beach and at the

Whitewood Mine near Wabamun. In the Forestburg/Halkirk area, thermal coal is strip-mined at the Paintearth and Diplomat mines near Forestburg, at the Vesta Mine near Halkirk, and at the Montgomery Mine (formerly Roselyn Mine) near Sheerness.

Some initial crushing of coal mined in the region is done at each mine, but most of the final sizing occurs at four receiving thermal electric generating stations, namely, Sundance, Keephills, Wabamun, and Battle River.

The dry preparation or crushing and screening of coal does not require the direct use of water. Principal freshwater withdrawals at all mines and preparation plants are for sanitary use, dust suppression and equipment maintenance. All water withdrawals may be regarded as consumed.

It is estimated that water use is approximately $0.01 \text{ m}^3/\text{t}$ of product coal for all mines in the region. Dust suppression water requirements may account for up to 90% of this amount, particularly in the more southerly mines.

None of the mines operating in Region 2 responded to the 1981 water use questionnaire. However, Statistics Canada and Environment Canada (unpub. data, 1982) estimate that 90% of the total freshwater intakes were obtained from surface water sources.

Water Use in Region 3

Thermal coal is strip-mined at six locations in Region 3. The Bienfait, Boundary Dam, Costello (formerly Klimax Mine), Souris Valley and Utility mines are located in the vicinity of Estevan. The Poplar River Mine (formerly Coronach Mine) is near Coronach, approximately 150 km west of Estevan (Fig. 1).

Primary crushing of coal mined in the region is done at each mine. Although the Bienfait and Costello mines have additional sizing capability, most of the final size reduction occurs at two receiving thermal electric generating stations, namely, Poplar River and Boundary Dam.

As in Region 2, water is not required in the preparation of coal mined in the region but is required at all mines for sanitary use, dust suppression and equipment maintenance. All water withdrawals may be regarded as consumed.

Water use at all mines is estimated at $0.01 \text{ m}^3/\text{t}$ of product coal. From information obtained in the 1981 water use questionnaire approximately 90% of total water intake was used for dust suppression and the remaining 10% for sanitary use (Statistics Canada/Environment Canada, unpub. data, 1982). Water use for equipment maintenance was not supplied or estimated.

Mines near Estevan obtained approximately 90% of total freshwater intakes from surface sources and the remaining 10% from public water utility systems (Statistics Canada/Environment Canada, unpub. data, 1982). Freshwater intakes at the Poplar River Mine were obtained from ground-water sources.

The coal seam at the Poplar River Mine is itself an aquifer. Dewatering of the mine area during 1983 amounted to approximately $22\,420 \text{ m}^3$ of water per day (P.J. Paine, IPB, EPS, pers. comm., 1984). A large portion of this amount is discharged directly to the surface water system, while a lesser amount is pumped to settling ponds prior to discharge. This dewatering process increases the potential for evaporative and seepage losses.

Water Use in All Regions

Estimates of total water use for coal mining and preparation in the study area for the year 1983 are shown in Table 7. These estimates are based primarily on Statistics Canada and Environment Canada water use questionnaire returns from individual coal mining companies.

Water use for coal mining communities and mine dewatering operations is not included in the questionnaires. These additional water requirements are discussed in the following section.

The wet preparation of thermal and metallurgical coal in Region 1 during 1983 was the most significant user of water in the study area. Coal

production in Region 1 represented 47% of the total production for the study area but was responsible for over 98% of all the water used. As wet preparation is not currently used in Regions 2 or 3, water use is minimal.

Table 7. Coal Production and Estimated Water Use by Region, 1983

Region	Total water use (m ³)	Total coal production (clean or as shipped) (10 ⁶ t)
Region 1	12 317 760	19.641
Region 2	144 300	14.43
Region 3	<u>77 550</u>	<u>7 755</u>
	12 539 610	41 826

Water systems currently used in preparation plants within Region 1 vary from partially open systems, with large intakes and minimal water recirculation and in-plant conservation, to virtually complete recycle (closed) systems, with very low intake of makeup water and little discharge from the process. These differences have led to large variations in the amount of water required per unit of coal produced, with a range of 0.06 to 1.85 m³ of water per tonne of coal.

Additional Water Requirements

Data obtained from surveys of individual coal mining companies include water use for mining and preparation, sanitary service, dust suppression and equipment maintenance but give no indication of additional water requirements for coal mining communities⁴ or withdrawals in mine dewatering operations.

⁴ Coal mining communities may be defined as communities developed solely for the purpose of providing supplies, services and housing to mine and preparation plant employees and their families.

Municipal water use requirements of coal mining communities have not been examined in this report. There are few coal communities in the study area at present, but new developments in remote regions such as northeastern British Columbia will include the construction of new communities. The water demands of these communities may be significant.

It has been estimated that mine dewatering to facilitate working of a coal seam may involve the withdrawal of up to approximately 0.6 m^3 of ground water per tonne of coal mined. This estimate is based on the Poplar River Mine in Saskatchewan and may be the extreme case, as the coal seam at this mine is itself an aquifer. Water withdrawn from the Poplar River Mine is discharged directly into a local surface water system.

In addition to potential disturbance of local ground-water regimes, future dewatering activities may result in significant water loss due to evaporation and seepage if this water is impounded for any reason, or for an extended period of time. Dewatering at the Poplar River Mine is estimated to be approximately $22\,420 \text{ m}^3/\text{day}$, and Petro-Canada's proposed Monkman Mine in northeastern British Columbia may require dewatering at a rate of $52\,000 \text{ m}^3/\text{day}$. The effects of dewatering are documented in Part B.

Reclamation of surface mined lands in the study area is stringently regulated, particularly in the plains regions (2 and 3) where strip-mining has in the past resulted in extensive land surface degradation. Irrigation has not been practised in any of the regions. In the future, however, revegetation of reclaimed lands may require the use of irrigation, particularly in areas where rainfall or soil moisture levels are insufficient to sustain plant growth.

Water Use in Other Sectors of the Economy

Water is an essential requirement for social and economic development and is particularly important to the resource-based economies that prevail in all three coal mining regions of the study area. The most valuable economic outputs in the study area are agriculture, mineral and fuel extraction, forest products and thermal and hydroelectric power generation. These activities are heavily dependent upon a reliable supply of water.

The demand for water in each region by all users and by the coal industry alone is shown in Table 8. Water is withdrawn for some uses (e.g., irrigation and manufacturing) and used *in situ* for others (e.g., hydroelectricity, fish and wildlife, and navigation).

REGION 1

Current coal mining and preparation activities in this region are concentrated in three areas (Fig. 1):

- (1) the East Kootenay area, centred on Sparwood in southeastern British Columbia
- (2) the Yellowhead area of west-central Alberta
- (3) the Wolverine area of northeastern British Columbia.

All three areas are relatively undeveloped and sparsely populated. Surface and ground-water resources are extensive and present demands from other sectors are low. The primary users are hydroelectric power generation, forest industry, recreation, fish and wildlife and mineral and fuel extraction. Coal mining and preparation accounts for approximately one quarter of all water withdrawn in the region.

Table 8. Water Demand by Region, 1981 (millions of cubic metres per year)

Region	All users		Coal mining and preparation		Coal as percent of all users	
	Withdrawal	Consumption	Withdrawal	Consumption	Withdrawal	Consumption
Region 1	44.58	13.34	10.58	Unknown	23.7	Unknown
Region 2	4000	2600	0.07	Unknown	<0.05	Unknown
Region 3	725	690	0.04	Unknown	<0.05	Unknown

Sources: Environment Canada (unpub. rep., 1983); Hess (1986).

REGION 2

Current coal mining and preparation activities within the region are concentrated in the Lake Wabamun area, approximately 70 km west of Edmonton, and in the Forestburg/Halkirk area, approximately 130 km southeast of Edmonton (Fig. 1). Both areas lie within the heavily populated and highly developed central Alberta region. Primary water use in this region is agricultural, municipal, recreational and industrial as well as for thermal power generation, manufacturing, and mineral and hydrocarbon extraction.

Surface and ground-water resources are more than adequate for present demands. Although coal mining and preparation activity accounts for less than 1% of water withdrawn and consumed, it is possible that local water supply problems may develop. In the Lake Wabamun area there are at least four major water users: agriculture, thermal power generation, recreation and coal mining. Continuing development in this area must give careful consideration to water planning and management.

REGION 3

Current coal mining and preparation activities in this region are concentrated along the south-central and southeastern margins of Saskatchewan, a lightly settled rural area with a declining population. As part of the southern half of the Saskatchewan-Nelson basin, this area is semi-arid and water short with few natural ground-water reservoirs and with cycles of wet and dry years (Prairie Provinces Water Board, unpub. rep., 1984).

Coal mining and preparation activity accounts for less than 1% of water withdrawn and consumed in the region.

Comparing consumption with available supplies for major sub-basins in southern Saskatchewan, Qu'Appelle, Souris and South Saskatchewan sub-basins may be defined as "water short."⁵ In addition, a number of

⁵ Water short, as defined by the Prairie Provinces Water Board (unpub. rep., 1984), is a condition in which consumptive use in a basin exceeds 50% of either the average supply in the 1976-77 drought years or the lowest recorded annual supply.

smaller streams such as the Poplar River are considered to have a "pent-up demand"⁶ for water (Prairie Provinces Water Board, unpub. rep., 1984).

The limited and variable water supplies in areas currently being mined for coal further aggravate conflicts among other users, such as agriculture, industrial, mineral and hydrocarbon extraction and thermal power generation.

⁶ Pent-up demand is a term used by the Prairie Provinces Water Board (unpub. rep., 1984) to describe basins in the Prairie Provinces that have been subject to water apportionment and rationing for many years; if water was diverted to these basins from other sources the pent-up demand would cause a further increase in rates of use.

New Coal Technologies and Water Demand

Development in new coal preparation, conversion, combustion and transportation processes, their individual and combined water demands and their likelihood of implementation must be included in any consideration of the impact these processes have in the overall water demand for a given region. This chapter summarizes the characteristics, current status, likelihood of implementation and possible locations of four new coal technologies:

- (1) coal slurry pipelines
- (2) flue gas desulphurization
- (3) advanced coal preparation
- (4) coal conversion (liquefaction and gasification).

COAL SLURRY PIPELINES

Coal is transported by unit train, truck and conveyor systems. The movement of coal over short distances, such as from the mine site to a preparation plant or from a mine site and/or preparation plant to a thermal power generating station, is accomplished primarily with large-capacity haulage trucks. Conveyor systems are conventionally used to transport run-of-mine coal over distances of up to 13 km such as at the Quintette, Bullmoose, Harmer, and Greenhills mines.

The long distance transport of coal from mines and preparation plants to domestic markets and to coal terminals for trans-shipment to export markets is by the unit coal train.

An alternative method of transporting coal over both long and short distances is by slurry transportation, i.e., pipelines through which coal is

pumped as a suspension in water or some other carrying medium such as methanol. Although liquids such as crude oil, methanol and liquid carbon dioxide have been examined as possible slurry transport media, coal suspended in water remains the slurry system with the greatest potential (Wasp, 1983).

A coal slurry pipeline would require a preparation plant, pumping station or stations, and dewatering and water clarification facilities at the discharge end. The amount of water required for a coal/water slurry pipeline is approximately 0.9 to 1.0 m³/t of coal transported. The slurry would consist of approximately 50% coal and 50% water by weight.

Water return lines have been suggested as a means of recycling water, but proposals for these have indicated that in every case it would be uneconomical. Alternative uses, however, have been proposed for recovered and treated coal slurry wastewaters. These uses include agricultural irrigation and thermal power plant cooling (Techman Engineering Ltd., 1983). If these alternative uses prove viable, water consumption would be reduced for pipelines which begin and end within the same watershed.

According to Techman Engineering Ltd. (1983), two long distance coal slurry pipelines have been proposed for the transportation of coal from the Yellowhead area of west-central Alberta to ports on the coast of British Columbia for export to the Pacific Rim countries, principally Japan:

- (1) The Coal Slurry Pipeline Feasibility Study (Fluor Canada Ltd., 1981), which represents the most recent definitive study on the subject, examines a slurry pipeline that would transport from 10.2 to 18.2 million tonnes of thermal coal per year (base and expanded cases, respectively) from Hinton, Alberta, to Kitimat, British Columbia, a distance of 1016 km. If a 50% weight/weight coal water slurry was used, this would require approximately 10.2 to 18.2 million cubic metres of water per year. Water should be supplied from the Athabasca River, the only river in the area capable of supplying this volume. Water withdrawals for both base and expanded cases would be made on a continuous basis. This would result in a reduced mean annual river flow of 0.17% for the base case (0.3% expanded case) or a reduced lowest monthly average flow of 1% for

the base case (1.85% expanded). These withdrawal rates are not considered to be sufficiently significant to impact the river flow patterns and adversely influence downstream river users. Table 9 presents estimates of water requirements for the base and expanded cases of the Hinton/Kitimat coal slurry pipeline.

Table 9. Water Requirements for the Hinton to Kitimat Coal Slurry Pipeline

	Base case	Expanded case
Coal throughput (t/yr)	10.2×10^6	18.2×10^6
Pipeline distance (km)	1016	1016
Slurry velocity (m/s)	1.83	1.83
Pipeline transit time* (day)	6.43	6.43
Water requirement for normal operation (m^3/yr)	10.2×10^6	18.2×10^6
Flushing rate (m^3/day)	45 216	80 640
Total flushing volume † (m^3/yr)	0.29×10^6	0.52×10^6
Partial flushing volume ‡ (m^3)	Variable	Variable
Minimum water requirement § (m^3/yr)	10.2×10^6	18.2×10^6
Maximum water requirement § (m^3/yr)	10.5×10^6	18.7×10^6

* Pipeline transit time = pipeline distance/slurry velocity.

† Total flushing volume is applicable only on decommissioning of the pipeline when the complete length of the pipeline is flushed. It is the product of flushing rate and pipeline transit time. In practice, this volume of water is used only once on decommissioning.

‡ Partial flushing volume is applicable to any portion of the pipeline that requires flushing. It will depend on distance involved and the time over which the flush acts. In practice, this volume of water may be used frequently, depending on pipeline operation.

§ Excludes partial flushing volume.

- (2) The proposed Coal West slurry pipeline would transport approximately 10 million tonnes of thermal coal per year from the Coalspur area of Alberta to the British Columbia coast, a distance of 1040 km. Assuming a 50% weight/weight coal water slurry, approximately 10 million cubic metres of water per year would be required. Water withdrawals from the McLeod River would occur during periods of high flow with a six-month supply held in a storage pond.

For the purposes of this study, it is assumed that a coal slurry pipeline will be operating in Region 1 under the medium and high scenarios; an estimated 10.5 million cubic metres of water per year will be used for the medium scenario and 18.7 million cubic metres per year, for the high scenario.

Although not a dedicated coal slurry pipeline, there is considerable interest in using the Trans Mountain oil pipeline as a dual-mode pipeline to batch transport both crude oil and coal slurries. The Trans Mountain pipeline is currently used to transport oil from Edmonton to Vancouver. Upon reaching Vancouver, the coal slurry would be pumped directly into tankers for shipment to Pacific Rim countries.

Due to ongoing environmental and socio-economic studies on the feasibility of dual-mode operation of the Trans Mountain oil pipeline, it is not possible at present to state whether the dual-mode operation will be accepted. A report by Monenco Consultants Ltd. (1985) has examined and identified the engineering pre-feasibility and the socio-economic and environmental concerns relating to the use of the Trans Mountain oil pipeline for batch transportation of crude oil and coal slurries. Scenarios of 2 and 5 million tonnes per year were considered. The report concludes that from an engineering consideration, batch transport of coal slurries in existing oil pipelines is technically feasible, although a high degree of powering of the pipeline for both scenarios would be required because of a high coal slurry density (75% by weight coal) and flow velocity to maintain turbulent flow conditions. From a socio-economic view, the main activities associated with pipelines (construction and operation aspects) are reduced as the pipeline is already in place. The only additional facilities required are extra pumping stations. The main impacts are expected to be in the towns of Hinton and Edson, with increases in coal production and slurry preparation.

One of the main environmental concerns with pipelines is the disruption which occurs during construction; this concern is eliminated by the use of the Trans Mountain pipeline. However, there is still some concern with respect to coal slurry spills and the impact of coal fines on the land and aquatic environments.

Water use for slurry preparation, as well as dewatering at the terminus, will decrease due to the use of a higher density slurry. As the slurry is destined for export, however, this water may be considered to be lost from the area from which it is abstracted. Estimated water requirements for the 2 and 5 million tonnes per year scenarios are summarized in Table 10.

Table 10. Estimated Water Requirements for the Trans Mountain Pipeline

	Scenarios	
	Base case	Expanded case
Coal throughput (t/yr)	2×10^6	5×10^6
Pipeline distance (km)	1146	1146
Slurry velocity (m/s)	1.4-1.6	1.4-1.6
Pipeline transit time * (day)	9.5-8.3	9.5-8.3
Slurry concentration (%)	60 (lower) 75 (higher)	60 (lower) 75 (higher)
Water requirement for normal operation † (m^3/yr)	0.8×10^6 (higher) 0.5×10^6 (lower)	2.0×10^6 (higher) 1.25×10^6 (lower)
Total flushing volume ‡ (m^3/yr)	334 632	334 632
Partial flushing volume (m^3/yr)	Variable	Variable
Minimum water requirement (m^3/yr)	0.83×10^6	1.58×10^6
Maximum water requirement (m^3/yr)	1.13×10^6	2.33×10^6

* Pipeline transit time = pipeline distance/slurry velocity.

† Based on coal slurry concentrations of 60% and 75%.

‡ Assumed: one flush per year.

FLUE GAS DESULPHURIZATION

Flue gas desulphurization refers to a process used to remove sulphur oxides (SO_x) from stack flue gases of coal-fueled power plants to control and limit acid gas emissions. The process is based on the solubility of sulphur oxide in water or an alkaline solution such as calcium oxide (CaO). In principle, flue gases from combustion pass through "scrubbers" containing an alkaline mist. The resulting blowdown product is calcium sulphate ($CaSO_4$) which, depending on quality, may be dewatered and sold as gypsum.

Flue gas desulphurization is not a component in the mining and preparation of coal, but it may play a significant role in the future development of mine mouth thermal power generation. Flue gas desulphurization is a water user in relation to coal consumption and as such, could pose a constraint on coal development in specific areas.

The total water needs for flue gas desulphurization systems in the year 2000 will depend on emission standards enforced for sulphur dioxide and on the average sulphur content of the coals burned. If emission standards in Canada were similar to standards in the United States, stack gases from thermal plants using subbituminous coal from Western Canada would not likely require flue gas desulphurization treatment because of the low sulphur content (0.3% to 0.8% sulphur). However, industries or power plants fired by bituminous refuse coal or certain B.C. lignites would likely require a flue gas desulphurization system. For Kootenay, British Columbia, a 600-MW plant burning refuse coal had been planned for operation within the study area but was subsequently deferred. It is assumed that future power plants in the study area will exist in the current form with no utilization of flue gas desulphurization processes by the year 2000.

Flue gas desulphurization processes currently in use outside Canada require large quantities of water, primarily for the wet scrubbing of combustion gases. A wet flue gas desulphurization system installed at a 600-MW thermal power plant would require the withdrawal and consumption of approximately $810\,000\text{ m}^3$ of water per year, or $0.27\text{ m}^3/\text{t}$ of coal input. Total annual coal input at the plant would be approximately 3.0 million tonnes of bituminous coal refuse with a heat value of 12 558 J/g, sulphur content of 0.8%, and moisture content of 35% (Environment Canada, unpub. rep., 1983).

ADVANCED COAL PREPARATION

Coal preparation plants in Canada presently rely on established physical and mechanical cleaning processes to achieve sulphur and ash reduction. These processes, involving operations such as crushing,

screening, flotation and heavy media separation, have been described. To remove more inorganic and organic sulphur and ash from coal, as environmental regulations become more stringent, it is necessary to develop more effective coal cleaning processes. Thus, the objectives of current research programs are to refine existing and investigate new physical, chemical and biological cleaning processes capable of removing greater amounts of sulphur and ash than is possible with current technology.

Potential advanced coal preparation may comprise the following coal cleaning technologies:

- (1) Physical coal cleaning
- (2) Chemical coal cleaning
- (3) Biological coal cleaning.

Physical Coal Cleaning

Existing coal cleaning processes rely mainly on the physical differences between coal, pyrite and the ash-forming minerals. For 1990 and to the year 2000, it is expected that conventional coal cleaning, as it exists today, will still be practised.

It is also reasonable to expect that the operation will be increasingly refined with possible lower water consumption for the same or increased coal production throughput. Improved water conservation and recycle practices at the preparation plants may result directly from increases in water demands due to competition from other sectors (industry, agriculture, urbanization).

New physical coal cleaning technologies that have the potential to complement, or in some cases, replace conventional coal cleaning processes are

- (a) Oil agglomeration
- (b) Spherical agglomeration - bacterial adsorption (SABA)
- (c) High gradient magnetic separation (HGMS)
- (d) Electrostatic coal cleaning.

Of these processes, only the electrostatic coal cleaning process has undergone field scale trials, which were conducted at the Picway Thermal Generating Station, Columbus, Ohio. As this process operates on dry, ultrafine coal, water is not required.

Oil agglomeration, expressly for the recovery of coal fines from conventional coal cleaning float-sink circuits, is expected to be in operation by 1990 (P.J. Paine, IPB, EPS, pers. comm., 1985). The remaining processes are currently in the laboratory stage of development and are not expected to be in operation by 1990.

By the year 2000, further refinements can be expected in SABA and HGMS.

Chemical Coal Cleaning

Chemical coal cleaning removes both inorganic and organic forms of sulphur using either oxidation reactions with air, oxygen or chemical oxidants or displacement reactions with sodium or calcium hydroxide to reduce these sulphur forms. All reactions are conducted in an aqueous medium, but as most of these processes are still in the laboratory stage with low throughput rates (Morrison, 1982), water usage figures are not available. For specific technical and cost-benefit reasons, chemical coal cleaning is not expected to be operational by 1990.

Biological Coal Cleaning

Biological coal cleaning processes use bacteria *Thiobacillus thiooxidans* and the thermophilic species *Sulfolobus acidocaldarius* to remove inorganic sulphur from coals through the biological oxidation of pyrite to sulphate. Organic sulphur is not removed (Detz and Barvinchak, 1979). These cleaning processes can clean a 20% weight/weight slurry (upper limit) and are capable of achieving between 90% and 95% pyrite sulphur removal. For a plant processing 8000 t/day of a 20% w/w slurry, the estimated water requirement is 40.0×10^6 L/day. However, up to 98% of this process water is recycled within the plant, with makeup water required only to replace the lost moisture content of the product coal.

Biological coal cleaning processes are still in the developmental stage in Canada and the United States, and are not expected to be operational in the study area by 1990.

COAL CONVERSION

The basic technology for converting coal into synthetic liquid fuel and gas has been available since the early 1920s. After a waning interest, owing to the advent of plentiful conventional oil and natural gas supplies as well as the use of nuclear power, coal liquefaction and gasification technologies are again receiving attention.

Coal Liquefaction

Conversion of coal into liquid fuels is achieved by increasing the hydrogen content of coal and may be accomplished directly by Bergius hydrogenation or indirectly by Fischer-Tropsch hydrogenation.

Direct Liquefaction

The synthoil process developed in the United States is one of a number of direct liquefaction processes and here will serve as a model for the estimation of water demands. The key elements in the synthoil process include contact of a slurry of feed coal in recycled coal-derived liquid enriched with hydrogen in a fixed-bed tubular reactor (O'Hara, 1981).

An integrated mine mouth plant for production of a low-sulphur fuel oil from coal using the synthoil process would include a coal preparation plant, slurry mixer, preheater reactor, and separation, purification, hydrogen production and compression plants. A source of water for steam production and quenching would also be required.

A synthoil plant producing 1.8 million cubic metres of low-sulphur fuel oil per year ($4910 \text{ m}^3/\text{day}$) would require 5 million tonnes of subbituminous C coal per year. Water demands for a direct liquefaction plant of this size are shown in Table 11.

Table 11. Water Demands for a Hypothetical Direct Coal Liquefaction Plant Using the Synthoil Process

	Water withdrawal (m ³ /yr)	Water consumption (m ³ /yr)
Processing	1 314 000	876 000
Cooling	3 394 062	3 394 062
Dust suppression	125 000	125 000
	<u>4 833 062</u>	<u>4 395 062</u>
Water use per unit coal input (m ³ /t)	0.97	0.88
Water use per cubic metre oil produced (m ³)	2.7	2.47

Note: Plant input of coal = 5.0 million tonnes per year.
Plant output of oil = 1.8 million cubic metres per year.

Source: Environment Canada (unpub. rep., 1983).

Indirect Liquefaction

With indirect liquefaction the feed coal is completely gasified to produce a synthesis gas consisting primarily of a mixture of hydrogen and carbon monoxide. The synthesis gas is purified to remove particulates and sulphur compounds and is then reacted in the presence of a catalyst at elevated temperatures and pressures to produce liquid products such as methane and higher boiling point hydrocarbons (O'Hara, 1981).

An indirect liquefaction plant producing 1.8 million cubic metres of gasoline per year (4910 m³/day) would require 7.0 million tonnes of subbituminous C coal per year. Water demands for a plant and cooling facility of this size are shown in Table 12.

Improved direct liquefaction processes are now under study in laboratories in United States and West Germany. During the mid-1970s, advanced coal liquefaction technology was expected to meet a significant

Table 12. Water Demands for a Hypothetical Indirect Coal Liquefaction Plant and Cooling Facility

	Water withdrawal (m ³ /yr)	Water consumption (m ³ /yr)
Processing	14 564 000	985 000
Cooling	3 650 000	3 650 000
Dust suppression	175 000	175 000
	18 389 000	4 810 000
Water use per unit coal input (m ³ /t)	2.63	0.69
Water use per cubic metre gasoline produced (m ³)	10.26	2.7

Note: Plant input of coal = 7.0 million tonnes per year.
Plant output of gasoline = 1.8 million cubic metres per year.

Source: Environment Canada (unpub. rep., 1983).

share of the United States oil demand by the mid-1980s. Since 1980, however, liquefaction process research and development activities have been substantially reduced. Direct liquefaction is unlikely to command much interest in Canada, however, because the oil sands offer more economical oil supplies (Dames and Moore, 1978). If shortfalls in world oil supply occur within the next 20 years they may lend credence to and hasten the commercialization of coal liquefaction in Canada.

A pilot plant capable of simultaneously processing heavy oil and coal to produce naphtha and distillates is expected to be in operation in early 1987 in Strathcona County, Alberta (Oilweek, January 28, 1985). The technology involved will be a combination of West German and Canadian coal liquefaction processes involving light hydrogenation of heavy crudes combined with coal liquefaction to produce high-quality, high-aromatic naphtha and distillates. Two commercial plants, each with a 50 000 to 60 000 barrel per day capacity, may be in operation by the 1990s.

Coal Gasification

The conversion of coal to a gas involves reacting coal with steam at very high temperatures and pressures. There are two principal routes for the conversion process. In the first, heat is supplied directly by combustion with air in the process, so that nitrogen (from the air) is mixed into the product gas. The ultimate product is a low-Btu gas which, after cleaning, can be used as a utility fuel for the generation of electric energy. Underground *in situ* coal gasification has been examined as a method for the production of low-Btu gas (Bodle and Heubler, 1981).

Alternatively, heat may be supplied to the gasification process by means that do not introduce nitrogen into the product gas. The ultimate product is a medium-Btu gas which after cleaning can be used directly as fuel or, through further processing, can be upgraded to high Btu-gas (synthetic natural gas [SNG]), hydrogen or synthesis gas (Bodle and Heubler, 1981). The Lurgi descending-bed gasifier is examined as a method for the production of medium-Btu gas.

Lurgi Descending-Bed Gasifier

In a 1975 report on the prospects for coal gasification in Alberta, the Alberta Energy Resources Conservation Board concluded that the Lurgi descending gasifier was of particular interest in Alberta (Dames and Moore, 1978). The Lurgi gasifier has thus been chosen as a model for the estimation of water demands by a typical coal gasification facility.

A mine mouth Lurgi gasification plant producing 2.58 million cubic metres of high-Btu gas (SNG) per year ($7080 \text{ m}^3/\text{day}$) would require 6.83 million tonnes of subbituminous C coal per year. Water demands for a plant of this size are shown in Table 13. Water is used during the processing for cooling, steam production and scrubbing and cooling of the gas. Water and steam are also required during the subsequent purification and methanation stages. In addition, water is required for the cooling tower, utility boilers and scrubbers and dust suppression.

Table 13. Water Demands for a Hypothetical Coal Gasification Plant Using Lurgi Descending-Bed Gasifiers

	Water withdrawal (m ³ /yr)	Water consumption (m ³ /yr)
Processing	1 870 000	1 830 000
Cooling	3 510 000	3 510 000
Dust suppression	<u>170 750</u> 5 550 750	<u>170 750</u> 5 510 750
Water use per unit coal input (m ³ /t)	0.81	0.81
Water use per cubic metre SNG produced (m ³)	2.15	2.14

SNG - Synthetic natural gas.

Note: Plant input of coal = 6.83 million tonnes per year.

Plant output of SNG = 2.58 million cubic metres per day.

Source: Environment Canada, unpub. rep. (1983).

Underground (In Situ) Gasification

In principle, underground gasification involves sinking wells from the ground surface into the coal bed, injecting the gasifying medium (steam and air or oxygen) and collecting the gas produced. This technique enables coal to be recovered indirectly from seams which are either too deep or too thin to be mined with existing mining technologies.

Water is required for the production of steam used in the gasification process and will be required if the hydraulic fracturing method is employed to link injection/production wells. Water quantity data are not available.

In Canada, an *in situ* gasification test was conducted on a thick seam of subbituminous coal at Forestburg, Alberta, in 1976. The results of the test indicated that synthetic gas can be produced from coal at costs

substantially below those predicted for frontier gas (Dames and Moore, 1978). The tests have been discontinued, however, and it is unlikely that underground gasification of coal will be utilized in the study area by the year 2000. In addition, there is at present a lack of markets for the low-Btu, high nitrogen gas produced by underground gasification.

The potential environmental hazards associated with coal liquefaction and gasification may be quite substantial (Cameron, 1980). This is particularly true for underground gasification because of the possibility of ground-water contamination by the highly toxic gas produced by this process. In areas relying on ground-water supplies this would prove catastrophic if pollution should reach an aquifer.

In view of the plentiful alternative sources of natural gas in Canada, it is unlikely that a commercial coal gasification plant, either conventional or *in situ*, will be operating in the study area by the year 2000. The overall limitation to further commercial development of liquefaction and gasification will depend on production costs of oil extraction from the tar sands (Athabasca) and the technical limitations imposed by the relatively low hydrogen/carbon atomic ratio in coal.

Coal Production and Water Use Forecasts

This chapter contains forecasts of thermal and metallurgical coal production and resultant water quantity requirements of the coal industry in the study area for the year 1990. A comparison is made between the present and predicted importance of coal industry water use relative to water use in all other sectors, both industrial and non-industrial. Finally, current and potential water resource management problems are reviewed with reference to current activities and planned development by the coal industry.

COAL PRODUCTION: CURRENT AND FORECAST

This section examines current and forecast production of thermal and metallurgical coal in the study area. In an effort to account for the full range of economic uncertainty implicit in forecasts of this type, low, medium and high coal production scenarios for the year 1990 were examined. This study initially undertook to forecast coal production to the year 2000 but, given current uncertainties in both domestic and export markets, it became evident that realistic forecasts beyond the year 1990 could not be made.

The low forecast is intended to reflect continued but slow growth in the coal industry with no significant economic upturn. The medium or most probable forecast adopts a more optimistic view and assumes a moderate growth rate with some degree of economic recovery, particularly within the export sector. The high forecast assumes a significant global economic recovery and maximum growth in the coal industry with all planned developments scheduled to 1990 becoming operational. An Environment Canada (unpub. rep., 1984a) study that details coal mine and preparation plant development in Canada was the primary source of information from which the high forecast data were derived.

Although the projected tonnages for the 1990 high forecast are unrealistically high, it was felt that an attempt should be made to reflect the maximum or worst case scenario with respect to the demands placed on the water supplies of each region. The coal production figures given under the high scenario are probably more realistic for the year 2000. Prior to the global recession which began to affect Canada's coal industry in 1982, forecasts for the year 2000 were well within range of the high forecast data presented in this report (see for example, Energy, Mines and Resources Canada, 1980: 100 to 165 Mt; Canada West Foundation, 1980: 100 to 154 Mt; Paine and Blakeman, 1983: 150 to 200 Mt).

Table 14. Coal Production by Region for Western Canada, 1983 and 1990
(millions of tonnes, clean coal or as shipped)

Region and province	Coal type	1983	1990		
			Low	Medium	High (up to)
Region 1					
British Columbia	Thermal	3.236	9.29	10.578	24.08
	Metallurgical	9.31	12.31	14.022	31.92
Alberta	Thermal	2.511	4.75	4.546	20.946
	Metallurgical	4.584	5.6	6.2	8.0
Total	Thermal	5.747	14.04	15.124	45.026
	Metallurgical	13.894	17.91	20.222	39.92
Region 2					
Alberta	Thermal	14.43	21.05	26.855	47.227
Region 3					
Saskatchewan	Thermal	7.755	9.53	10.2	12.06
Total all regions	Thermal	27.932	44.62	52.179	104.313
	Metallurgical	<u>13.894</u>	<u>17.91</u>	<u>20.222</u>	<u>39.92</u>
		41.826	62.53	72.401	144.233

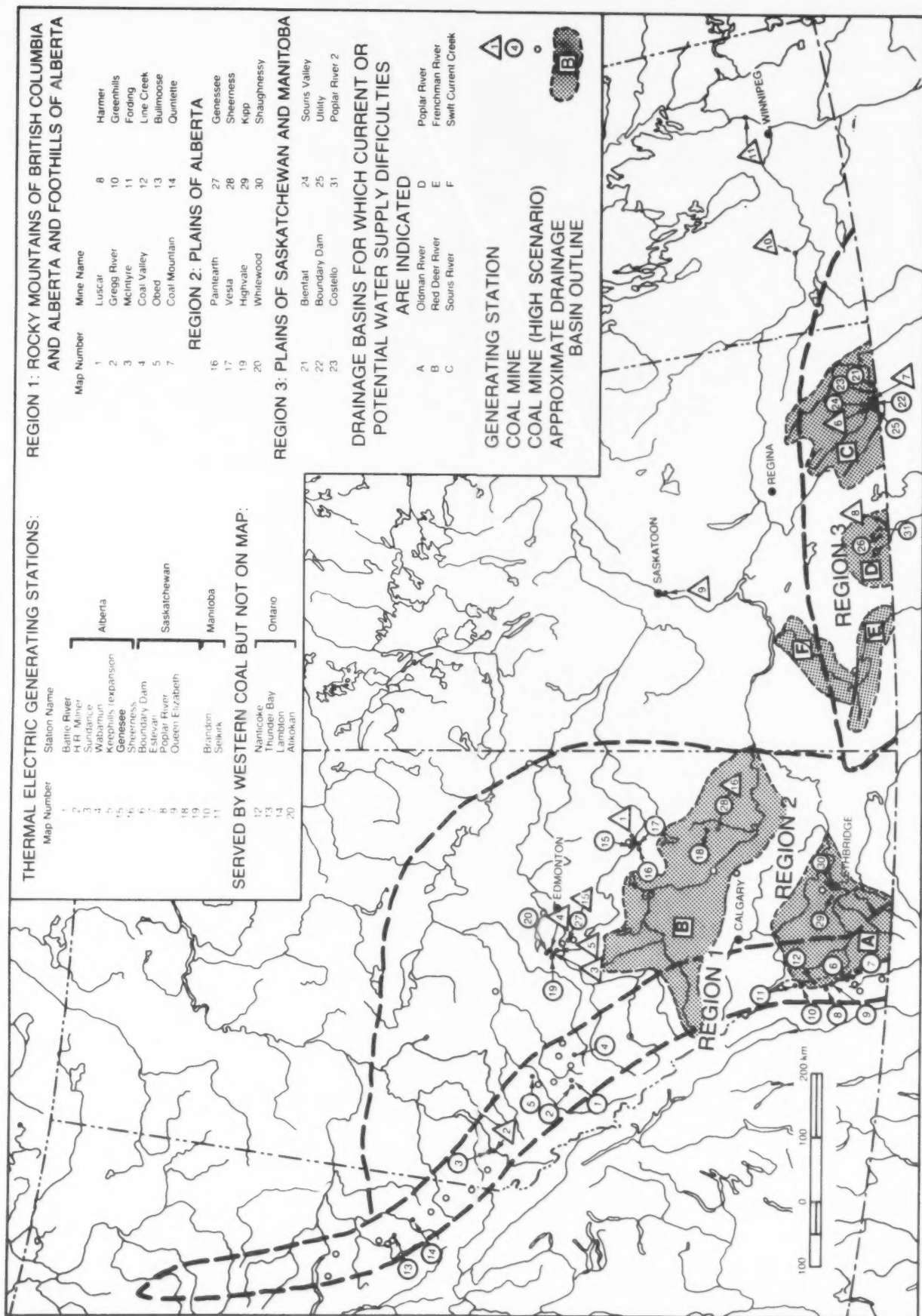


Figure 2. Coal mines and thermal electric generating stations assumed operational in 1990, medium scenario.

Coal production for 1983 and forecasts for 1990 are given in Table 14. A detailed description of the criteria used to derive the forecast data for each region is provided in the subsections which follow. The locations of existing and planned mines are shown in Figure 2.

Region 1

Under the low forecast it is assumed that no new mines will be developed in Region 1 and that slightly increased coal production will occur as a result of the expansion of existing mines. The medium forecast assumes one new mine development in northeastern British Columbia and greater expansion of existing mines than indicated in the low forecast. The high forecast assumes extensive new mine development in northeastern and southeastern British Columbia and in the Yellowhead area of Alberta in addition to increased production from existing mines. Table 15 lists the names of mines currently operating in Region 1 and the names of mines assumed to be operating under the low, medium and high scenarios.

Region 2

Under the low forecast it is assumed that two new mines, namely Genesee and Sheerness, will be developed in Region 2 and that an average annual increase in coal production of approximately 5.5% will occur as a result of the expansion of existing mines to supply coal to thermal electric generating stations. The medium forecast assumes a 5.5% annual production increase plus four new mines, Genesee, Sheerness, Kipp and Shaughnessy. The high forecast assumes extensive new mine development in all parts of the region in addition to a 5.5% annual production increase from existing mines. Table 16 lists the names of mines currently operating in Region 2 and the names of mines assumed to be operating under the low, medium and high scenarios.

Table 15. Current and Planned Coal Mines in Region 1, 1983 and 1990

Location	1983	1990		
		Low	Medium	High
Yellowhead area Alta.	McIntyre Gregg River Luscar Coal Valley	McIntyre Gregg River Luscar Coal Valley Obed Marsh	McIntyre Gregg River Luscar Coal Valley Obed Marsh	McIntyre Gregg River Luscar Coal Valley Obed Marsh Copton-Meadowlark Hinton-East/West McLeod River Mercoal Nordegg Dentherm/Robb Bryan Mountain
Northeastern B.C.	Bullmoose Quintette	Bullmoose Quintette	Bullmoose* Quintette	Bullmoose Quintette Belcourt Dowling Creek Burnt Creek Carbon Creek Peace River Canyon Hasler Creek Monkman Pass Mount Spieker Saxon Sukunka Willow Creek
Southeastern B.C.	Fording River (Taylor) Line Creek Harmer Michel Greenhills Coal Mountain	Fording River (Eagle) Line Creek Harmer Greenhills Coal Mountain	Fording River (Eagle) Line Creek Harmer Greenhills Coal Mountain	Fording River (Eagle) Line Creek Harmer Greenhills Coal Mountain Corbin Creek Elk River Valley Hosmer-Wheeler Sage Creek - Flathead River
Southwestern Alta.	Coleman			

* The medium forecast assumes one new mine in northeastern British Columbia; this mine will be one of those listed under the high scenario.

Sources: Environment Canada (unpub. rep., 1984a); P.J. Paine, IPB, EPS (pers. comm., 1984 and 1985).

Table 16. Current and Planned Coal Mines in Region 2, 1983 and 1990

1983	1990		
	Low	Medium	High
Diplomat			
Highvale	Highvale	Highvale	Highvale
Paintearth	Paintearth	Paintearth	Paintearth
Vesta	Vesta	Vesta	Vesta
Whitewood	Whitewood	Whitewood	Whitewood
Montgomery	Genesee Sheerness	Genesee Sheerness Kipp Shaugnessy	Genesee Sheerness Kipp Shaugnessy Atlas Buffalo Hills Forestburg Heatburg Judy Creek north and south Keephills Picture Butte Star Key Wetaskiwin

Sources: Environment Canada (unpub. rep., 1984a); P.J. Paine, IPB, EPS (pers. comm., 1984 and 1985).

Region 3

Production increases of 3.0% and 4.0% are assumed under the low and medium forecasts, respectively. It is also assumed for both scenarios that one new mine, referred to as Poplar River 2, will open subsequent to the planned closing of the Poplar River Mine in 1990. This will not alter the number of mines in Region 3. The high forecast assumes a 5.0% increase in production plus two new mines, Rock Glen and a mine now known as Southwest Saskatchewan. Table 17 lists the names of mines currently operating in Region 3 and the names of mines assumed to be operating under the low, medium and high scenarios.

Table 17. Current and Planned Coal Mines in Region 3, 1983 and 1990

1983	1990		
	Low	Medium	High
Bienfait	Bienfait	Bienfait	Bienfait
Boundary Dam	Boundary Dam	Boundary Dam	Boundary Dam
Costello	Costello	Costello	Costello
Poplar River	Poplar River 2	Poplar River 2	Poplar River 2
Souris Valley	Souris Valley	Souris Valley	Souris Valley
Utility	Utility	Utility	Utility
			Rock Glen
			Southwest Saskatchewan

Sources: Environment Canada (unpub. rep., 1984a); Saskatchewan Environment (pers. comm., 1984).

Summary

The bar graph in Figure 3 depicts current and forecast coal production by coal type and region. The low and medium forecast data compare favourably with official Energy, Mines and Resources Canada (EMR) forecasts for 1990 (P.J. Paine, IPB, EPS, pers. comm., 1984). As discussed earlier, the high forecast figure of 144 million tonnes, compared with the EMR figure of 82 million tonnes, is indicative of the worst case scenario and suggests a period of substantial development between 1990 and the year 2000. EMR forecasts and those derived in this report (in megatonnes) are summarized as follows:

Source	1990		
	Low	Medium	High
Energy, Mines and Resources Canada	62.0	71.0	82.0
This study	62.53	72.4	Up to 144.2

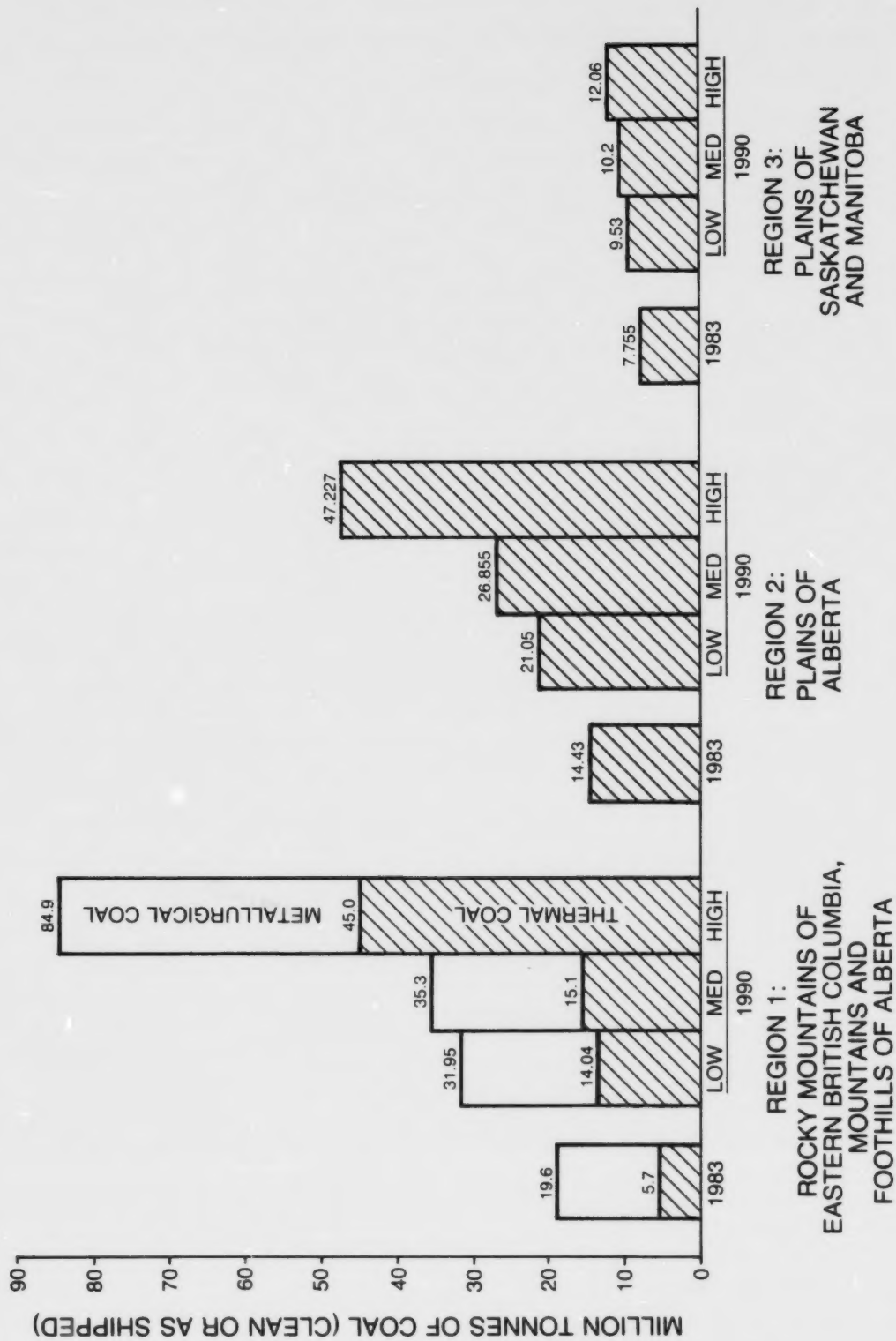


Figure 3. Current and forecast coal production by type and region, 1983 and 1990.

A detailed analysis of the complex domestic and export coal markets is contained in a report by Canada West Foundation (1980), which states that future growth in the demand for coal will be derived from five basic sources:

- (1) Exports
- (2) Electric power industry in Western Canada
- (3) Ontario electric power industry (Ontario Hydro)
- (4) Canadian (particularly in Western Canada) industrial thermal requirements
- (5) Coal conversion (conversion of coal to liquid or gas).

Growth in these individual sectors has been carefully examined by the Canada West Foundation (1980) and by Environment Canada in an unpublished report (1983) in which water demands by the coal industry are estimated on a regional basis.

The emphasis of this study is to examine current and forecast regional water use demands by the coal industry based on specific development plans throughout each region rather than overall regional production forecasts. This approach permits the identification of existing and potential water supply and demand conflicts.

WATER DEMANDS: CURRENT AND FORECAST

This section examines current and forecast water quantity requirements of the coal industry in the study area. Water quantities were computed on the basis of past and current documented water use in coal mining and preparation facilities in the study area and on estimates derived in this report for conventional mining and preparation and for new coal technologies (Table 18). These data were applied to low, medium and high coal production forecasts for the year 1990 to obtain total water quantity requirements.

Current and potential water supply and demand conflicts are reviewed, and water use by the coal industry is compared with water use by all other sectors, both industrial and non-industrial.

Table 18. Current and Forecast Water Requirements for Coal Mining and Preparation (m³)

Region	1983	1990		
		Low	Medium	High
Region 1	12 317 760	19 928 230	29 849 470*	60 763 100†
Percent increase		46	142	393
Region 2	144 300	210 500	2 192 500	4 210 230
Percent increase		46	1420	2820
Region 3	77 550	96 300	102 000	120 600
Percent increase		23	32	56

* Includes 10 500 000 m³/yr for slurry pipeline water use.

† Includes 18 700 000 m³/yr for slurry pipeline water use.

Methodology

Water demands for current and planned coal mines and preparation plants were determined by applying water use coefficients (i.e., amount of water required per tonne of clean or shipped coal) to production data. These coefficients were derived using information and numerical data contained in Statistics Canada/Environment Canada water use questionnaires for 1981. For mines that either did not respond to the water use questionnaires or began operations subsequent to 1981, the following information was examined to assign a coefficient of water use and to estimate total annual water requirements:

- (1) Coal type, rank and field or deposit
- (2) Type and size of mining operation
- (3) Type and degree of preparation
- (4) Principal use and destination of product coal
- (5) Similarity(ies) with operations for which water use data exist.

The derived and assumed water use coefficients were applied to current and forecast coal production data for mines within each region to obtain total water use for mining and preparation. Additional water requirements for new coal technologies are added to mining and preparation water use.

Estimated water use for 1983 and forecasts for 1990 are given in Table 18. The subsections which follow review current and forecast water use within each region.

It should be noted that rates of water use, as referred to in the following subsections, are based on the total water withdrawal or requirement at each facility on an annual basis. Consumption data are not known and cannot be derived from the water use questionnaires. In Regions 2 and 3, consumption is assumed to be 100% of the withdrawal amounts, whereas in Region 1 consumption can vary greatly from one facility to the next. Recently quoted figures for consumption range from 31% (Environment Canada, unpub. rep., 1983) to 50% in an Athabasca River Basin Study (Erxleben, 1982). The latter figure refers to consumption of water used in the coal preparation process and would be higher if it included the consumptive use of water for dust suppression, sanitary service and equipment maintenance and washing.

Region 1

All of the coal produced in Region 1 during 1983 was subjected to wet preparation. As indicated in Chapter 2, thermal coal from the Foothills area and all metallurgical coal require more cleaning and generally greater water use than thermal coal from the mountain areas.

Based on the Statistics Canada questionnaires, water use at mines and preparation plants in this region varied from 0.06 to 1.85 m³/t of product coal. For comparison, a study of coal cleaning in the United States by Hutton and Gould (1982) reveals an even wider range of water use, from 0.003 to 2.5 m³/t of product coal.

Although rates of water use vary widely, the majority of operations in Region 1 require from 0.4 to 0.7 m³/t of product coal. Rates are the highest in the East Kootenays of southeastern British Columbia where most mines require 0.6 to 0.7 m³/t of coal. Water use at all but one or two other mines in Region 1 is reduced to between 0.4 and 0.5 m³/t of coal.

Current and forecast water requirements for the region are listed in Table 18. Under the low and medium scenarios, increased water demands are primarily due to the expansion of mines currently in operation. Increased water demands under the high scenario are the result of extensive new mine development in northeast and southeast British Columbia and the Yellowhead area of Alberta. Water use for the operation of a coal/water slurry pipeline from the Yellowhead area to Kitimat, British Columbia, has been included in the medium and high scenarios. Water is required for slurry preparation and for emergency flushing purposes. Approximately 0.9 to 1.0 m³ of water is required per tonne of coal transported and 100% of this amount is consumed and presumably discharged into the Pacific Ocean.

Region 2

All of the coal produced in Region 2 during 1983 was crushed and dry-screened with no direct use of water in the preparation process. None of the mines operating in 1983 responded to the Statistics Canada questionnaire. Therefore the water use coefficients for these mines were based on information presented in Chapter 2 of this report and on water use questionnaire data for mines in Saskatchewan. Water use for all mines in the region is assumed to be at a rate of 0.01 m³/t of product coal. All of this water is consumed.

Current and forecast water requirements for the region are listed in Table 18. Planned development under the medium and high scenarios includes a number of mines in south-central Alberta expected to produce bituminous coals which will undergo wet preparation (Environment Canada, unpub. rep., 1984a; P. J. Paine, IPB, EPS, pers. comm., 1984). The water requirement of these mines is assumed to be at a rate of 0.4 m³/t of product coal. From what is

known about the coal in this area it is reasonable to assume that preparation and water use will be comparable with mines in the Yellowhead area of Region 1.

Region 3

All of the coal produced in Region 3 during 1983 was crushed and dry-screened with no direct use of water in the preparation process. Based on Statistics Canada questionnaires water use at all currently operating mines in the region is estimated to be $0.01 \text{ m}^3/\text{t}$ of product coal. All of this water is consumed.

Current and forecast water requirements for the region are listed in Table 18. Planned development under all scenarios assumes continued water use at a rate of $0.01 \text{ m}^3/\text{t}$ of product coal.

Summary

Current and forecast coal production water demands by region are illustrated in Figure 4. Table 19 provides a comparison of current and forecast (medium scenario) coal production water use in relation to water use

Table 19. Current and Forecast Water Demands for Coal Production and for all Sectors, 1983 and 1990

Region	1983			1990		
	All sectors*	Coal mining and preparation	Coal as percentage of all users	All sectors*	Coal mining and preparation	Coal as percentage of all users
Region 1	328.92×10^6	12 317 760	3.74	392.95×10^6	29 849 470	7.6
Region 2	3418.9×10^6	144 300	0.004	$4 071.29 \times 10^6$	2 192 500	0.054
Region 3	611×10^6	77 550	0.013	709×10^6	102 000	0.014

* Data from Environment Canada (unpub. rep., 1983) and Tate (1985).

Note: Coal (mining and preparation) water use for 1990 assumes the medium or most probable scenario.

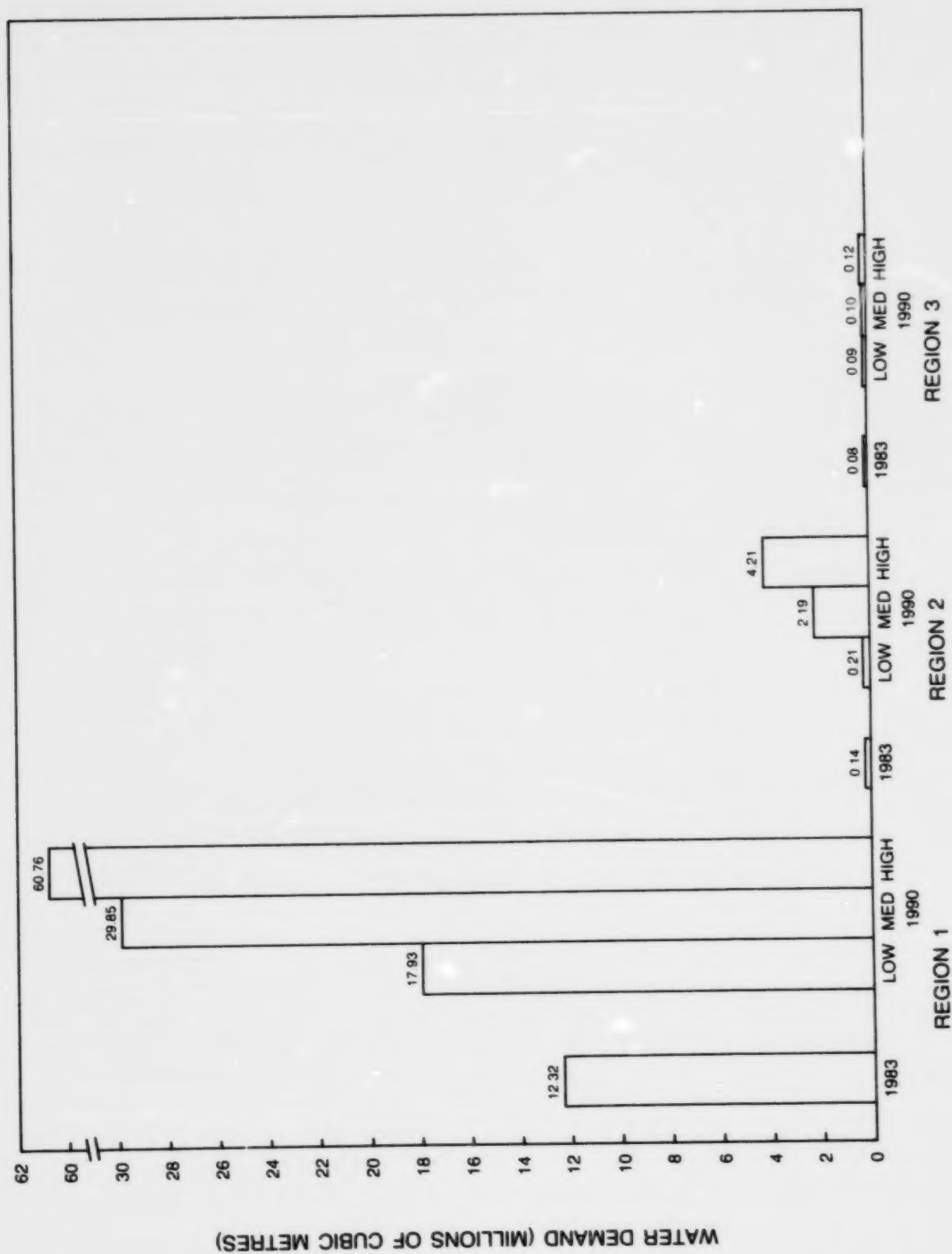


Figure 4. Current and forecast water demands for coal production, 1983 and 1990.

by all sectors. Water demands for coal mining and preparation are the highest in Region 1 where all coal produced in the region during 1983 was subjected to wet preparation. The East Kootenay and Yellowhead areas, respectively, accounted for 58% and 41% of total coal production water use in Region 1. Water use at the two mines in the Wolverine area, which commenced operation in late 1983, should account for approximately 15% of the region's total.

The Lake Wabamun and Forestburg/Halkirk areas of Region 2 accounted for 80% and 20%, respectively, of total coal production water use in the region during 1983.

Mines in the vicinity of Estevan accounted for 70% of total coal production water use in Region 3 during 1983. The remaining 30% was used by the Poplar River Mine near Coronach.

Under the *low scenario*, water demands in all three regions are assumed to increase as a result of the expansion of existing facilities and/or production capacities. It is estimated that water use in 1990 will be 46% higher than in 1983 for Regions 1 and 2, and 23% higher for Region 3.

The *medium scenario* assumes the development of new mines in Regions 1 and 2 and thus large new demands for water, particularly in Region 2 where water use in 1990 is expected to increase fourteenfold over 1983 levels. Water use in Region 1 is expected to increase by 142% and in Region 3, by 32%.

The *high scenario* assumes extensive new development in Regions 1 and 2 with large new demands for water in the East Kootenay, Wolverine and Yellowhead areas of Region 1 and in the Forestburg/Halkirk, Lake Wabamun and south-central areas of Region 2. Water use in 1990 is expected to increase fourfold over 1983 in Region 1 and almost thirtyfold in Region 2. Water use in Region 3 under the high scenario is expected to increase by 56% over 1983 levels, primarily because of the development of new mines in southwest Saskatchewan and in the Coronach area but also due to the expansion of existing facilities.

EXISTING AND POTENTIAL WATER SUPPLY PROBLEMS DUE TO WATER USE BY THE COAL INDUSTRY

Current estimated coal production water use as a proportion of total water use by all sectors is approximately 3.7% in Region 1 but less than 1% in both Region 2 and Region 3 (Figure 4 and Table 19). Although coal production ranks high as a water-using sector in Region 1, supplies in the region are abundant and there is little competition from other sectors. In Regions 2 and 3, however, total water demands by all sectors are very high in relation to supply and competition among users is great.

Examination of water use at current and planned coal developments in each region has revealed a number of existing and potential water supply problems in the southern third of Alberta and Saskatchewan (Regions 2 and 3), an area served by the Saskatchewan-Nelson River system. This can be described as a semi-arid, water-short area with a limited number of natural reservoirs and with cycles of wet and dry years. Summer rainfall is unreliable and sparse, and potential evaporation exceeds precipitation in many areas (Prairie Provinces Water Board, unpub. rep., 1984).

The Prairie Provinces Water Board (unpub. rep., 1984) lists a number of sub-basins in the study area that currently are water short and others where apportionment and rationing have been imposed for many years, creating a pent-up demand.

In Region 2, coal developments are planned for the water-short Oldman River sub-basin and for the Red Deer sub-basin, which is now experiencing pent-up demands and facing potential water shortages by the year 2000.

Planned development in the *Oldman* sub-basin includes two bituminous mines and wet preparation plants (Kipp and Shaughnessy) under the medium scenario, and an additional mine and wet preparation plant (Picture Butte) under the high scenario (Fig. 2).

One proposed mine (Sheerness) is planned for the *Red Deer* sub-basin under the medium scenario and two additional mines (Atlas and

Heatburg) have been included under the high scenario. These new mines and a thermal electric generating station planned at Sheerness for 1985/86 will result in additional large water demands. The Prairie Provinces Water Board (unpub. rep., 1984) suggests that this basin will be water short by the year 2000.

Seventeen new thermal electric generating stations with an estimated total capacity of 7600 MW are planned for Region 2 by the year 2000 (Monserco, 1983). The locations of 11 of these units are not known, but many are expected to be mine mouth plants fired by coal from mines listed under the high scenario. Total annual water withdrawals for a 1000-MW plant are approximately $27 \times 10^6 \text{ m}^3$ (Erxleben, 1982).

In Region 3, coal developments are planned for the Souris River sub-basin which is now water short and for the Poplar River, Frenchman River and Swift Current Creek sub-basins, which currently are experiencing pent-up demands.

The continued operation of mines and thermal electric generating stations in the *Souris* sub-basin may contribute to a lowering of ground-water levels in the Estevan aquifer (Environment Canada, unpub. rep., 1984b). Two additional generating stations with an estimated total capacity of 600 MW are planned for the area by 1990 (Monserco, 1983).

The Poplar River Mine and thermal electric generating station use surface and ground water from the *East Poplar River* sub-basin. Operation of the generating station results in diminished water supply and dewatering of the coal seam has extended the ground-water cone of depression to within 800 m of the United States/Canada border (Environment Canada, unpub. rep., 1984b).

In 1990, the Poplar River Mine will be closed and a new mine opened north of the present site. The new mine, which will service the Poplar River thermal electric generating station, will be located north of the aquifer, thereby alleviating further ground-water depression.

At present, no coal mines or thermal electric generating stations operate in the *Swift Current Creek/Frenchman River* sub-basins, but one new mine (Southwest Saskatchewan) is planned for the area under the high scenario, resulting in greater demand on water supplies.

Conclusions

Water quantity requirements for the coal industry in Western Canada were estimated by applying water use coefficients to existing (1983) and forecast (1990) coal production data. The coefficients were derived using available water use data and by examining the type of mining and degree of preparation employed at each coal facility. The following conclusions have been reached:

1. Water use data at Canadian coal facilities are available for the most recent survey year (1981) from official government sources. However, these data were not available for all coal mines in Western Canada and could not be used to determine total water withdrawal and consumption.
2. A wide variation in water use between mines disallowed extrapolation to those coal facilities *without* water use data. For such cases, a water use coefficient was assigned, based on similarities with operations for which water use data exist. The greatest water use requirement is for wet coal preparation.
3. For *Region 1*, water use ranged from a minimum of 0.06 m^3 per tonne of coal produced to a maximum of 1.85 m^3 , but was generally between 0.4 and 0.6 m^3 per tonne of coal produced. For *Region 2* and *Region 3*, water use was estimated to be 0.01 m^3 per tonne of coal produced. The comparatively larger amount of water used in *Region 1* is due to wet coal cleaning which is only performed at facilities in this region. Water use in *Regions 2* and *3* is primarily for dust suppression.
4. Compared with the water demand from other sectors, such as agriculture, irrigation, industrialization and urbanization, coal mining and preparation currently (1983) accounts for approximately 3.74% of the total water use in *Region 1*, 0.004% in *Region 2* and 0.013% in *Region 3*.

5. By the year 1990, *coal production* is expected to exceed the 1983 production figures by 80% in Region 1, 86% in Region 2, and 32% in Region 3. Consequently, water demands will also increase by 142% in Region 1, 1420% in Region 2 and 32% in Region 3. The large increase in water use in Region 1 is due to the installation of wet coal preparation at all projected new mines and to the addition of a coal/water slurry pipeline in the Yellowhead area. The large increase in Region 2 is due to the use of wet preparation at new mine developments in the south-central part of the region.
6. As a percentage of *total water use* in the three regions, water demands for coal mining and preparation by the year 1990 are expected to be 7.6% in Region 1 (an increase from 3.74% in 1983), 0.054% in Region 2 (an increase from 0.004% in 1983), and 0.014% in Region 3 (an increase from 0.013% in 1983).
7. There is sufficient supply in Region 1 to meet anticipated demands. In Regions 2 and 3, several existing and future coal developments are in sub-basins which are water short or may become water short by the year 1990. These include the Oldman and Red Deer sub-basins in Region 2 and the Souris, East Poplar and Swift Current Creek/Frenchman River sub-basins in Region 3.

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Part B
Influence on Ground Water



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Introduction

COAL INDUSTRY IN CANADA

The demand for coal increased dramatically between 1970 and 1981. In 1979, the Canadian coal industry was predicting a three- to fourfold increase in production by the year 2000 (Cobban, 1979). In 1982, however, a global economic recession began, a world oil glut resulted in a decrease in the price of oil, and major cutbacks in coal demand were made by Japan, the largest consumer of Canadian coal. Although this has had a moderating effect on the coal industry, annual production increases since 1981 have been approximately 5% and new mines have opened in British Columbia and Alberta. Current predictions are for a slow but steady recovery and a twofold increase in production by the year 2000 (Page, 1983; J.D. MacDonald, B.C. Coal Guidelines Steering Committee, pers. comm., 1983; see Part A of this report).

It is anticipated that production from coal mines in Western Canada will be maintained at approximately 90% of the Canadian total. Although a large proportion of future coal production will come from existing mines, significant new mine development is expected in many parts of Western Canada (see Part A of this report).

WATER RESOURCES AND THE COAL INDUSTRY

Water is required, often in large quantities, for the mining and preparation of coal, and concerns have been raised over the environmental impact of an increase in coal mining activity on surface and ground-water quality and supply.

The surface water system of Western Canada is dominated primarily by the Saskatchewan-Nelson River system and, to a lesser extent, by the upper basins of the Mackenzie and Missouri rivers. Streamflow, particularly in the southern half of the Saskatchewan-Nelson basin, is highly variable and there are few naturally occurring reservoirs. Numerous man-made impoundments have been constructed for streamflow regulation to provide a dependable supply for a variety of purposes (Prairie Provinces Water Board, 1984).

Ground water accounts for 22.5% of total water use in British Columbia, 5% in Alberta, 43% in Saskatchewan and 22% in Manitoba (Prairie Provinces Water Board, 1984; Hess, 1986).

PROJECT BACKGROUND

The following study was prepared as part of a project initiated by the Environmental Protection Service of Environment Canada to develop environmental protection criteria and/or technologies to ensure that ground-water systems in Western Canada will not be adversely affected by new or expanding coal mining and preparation facilities. The project was divided into two separate studies, which make up Parts A and B of this report.

Part B is a study of the ground-water resources in the coal-producing regions of British Columbia, Alberta, Saskatchewan and Manitoba.

The objectives of this study are

- (1) To assess the ground-water resources of Western Canada in relation to their ability to meet the predicted needs of coal industry expansion to the year 1990.
- (2) To assess the impact of coal mining and preparation on the amount, distribution and quality of ground water.

The emphasis of this study is on ground water for the following reasons:

- (1) Most of the least expensive and readily available surface sources of water have been developed already and are hard pressed to provide an adequate supply (Prairie Provinces Water Board, 1984)
- (2) A larger volume of ground than surface water is available (Huisman and Olsthoorn, 1983)
- (3) Ground water is as yet largely untapped
- (4) Aquifers can be used to store surface water without large evaporative losses and degradation of water quality (Huisman and Olsthoorn, 1983).

STUDY AREA

This study focusses exclusively on Western Canada. Although eight provinces contain deposits of coal, an assessment of Canadian coal reserves indicates that approximately 90% of all coal in mineable seams¹ occurs in British Columbia, Alberta and Saskatchewan (Romaniuk and Naidu, 1984). In addition, recent studies indicate that the majority of new coal mines planned for development by the year 2000 will be located in Western Canada (Environment Canada, 1984; Part A of this report).

On the basis of coal rank and age, and physiography, the study area was divided into three regions:

- (1) The Rocky Mountains of eastern British Columbia and the mountains and Foothills of Alberta (upper Jurassic to lower Cretaceous bituminous coals)

¹ Coal in mineable seams is defined as that part of measured and indicated resources of immediate interest that can be considered for mining using current technology and economics, before there is an allowance for mining losses.

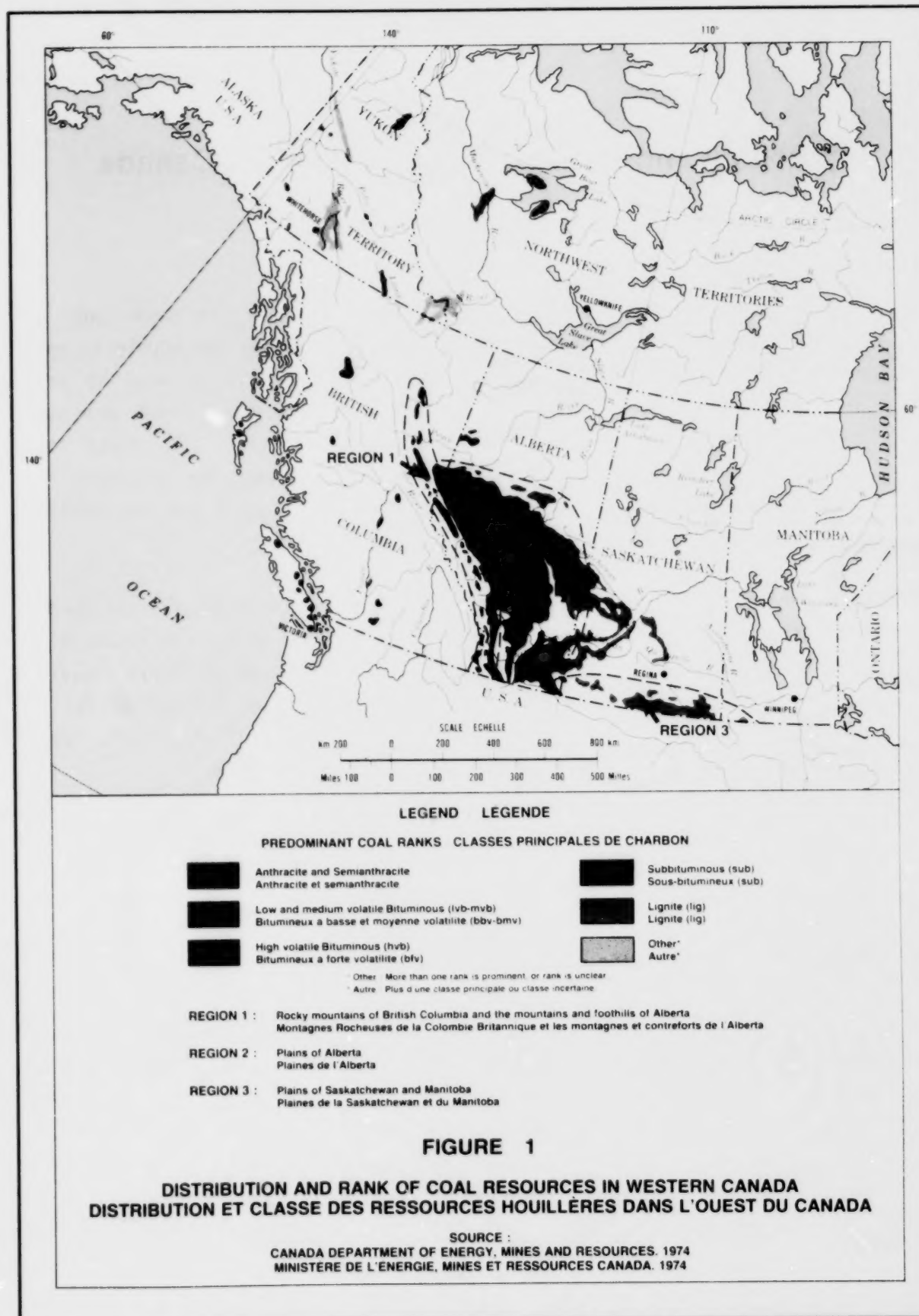
(2) The Plains of Alberta (upper Cretaceous to lower Tertiary subbituminous coals)

(3) The Plains of Saskatchewan and Manitoba (Tertiary lignitic coals).

The regions are delineated on Figure 1, which also shows the distribution and rank of coal resources in Western Canada. The locations of active and planned coal mines within each region are indicated on Figure 2 (in pocket).

The dynamic nature of hydrology and hydrogeology makes it difficult to assess ground-water resources within the confines of each region; in the following discussions, it has often been necessary to refer to areas beyond or overlapping the study region boundaries.

A description of the geology and hydrogeology of formations in Western Canada is contained in Appendix A; the stratigraphy of the region is illustrated in Appendices B and C.



Hydrology and Hydrogeology of Western Canada

This chapter provides an examination of the hydrology and hydrogeology of Western Canada with a view to assessing the supply of water available for future development of the coal industry, as well as other water-using sectors. Currently, available ground-water data are site specific, and as yet there is not sufficient information to obtain total available ground-water volumes in each region. However, the data were used to show the location of aquifers yielding greater than 8 L/s and aquifers yielding greater than 30 L/s (Fig. 2, in pocket).

The chemical quality of ground water, or water chemistry, is used to determine the origin of the water and its location along the ground-water flow path. The chemical constituents and concentration of total dissolved solids in ground water are the primary determinants of its suitability for municipal, industrial and agricultural use. The following is a brief discussion of water chemistry in the Western Canadian context.

As ground water moves along its flow path, the water chemistry is altered by the effects of chemical processes. Ground water will generally increase in total dissolved solids and in most of the major ions (i.e., HCO_3^- , Cl^- , SO_4^{2-} , Ca^{2+} , Mg^{2+} , Na^+ + K^+) from recharge to discharge areas, evolving gradually toward the composition of seawater.

For large sedimentary basins, such as Western Canada, a chemical sequence corresponds, in a general way, with depth. The chemical profile evolves from one of bicarbonate water and low dissolved salts in the upper zone, to water dominated by the sulphate anion in the intermediate zone and, finally, to water characterized by high chloride concentrations and high total dissolved solids in the lower zone with sluggish ground-water flow (Freeze and Cherry, 1979).

Bicarbonate-type waters occur close to recharge areas and where the flow system is short and active; sulphate-type waters are common in areas of ground-water discharge, areas of low permeability, and areas of slow ground-water movement, such as in areas of extensive flat topography. These associations have been shown by Tokarsky (1974).

REGION 1

Surface Water Environment

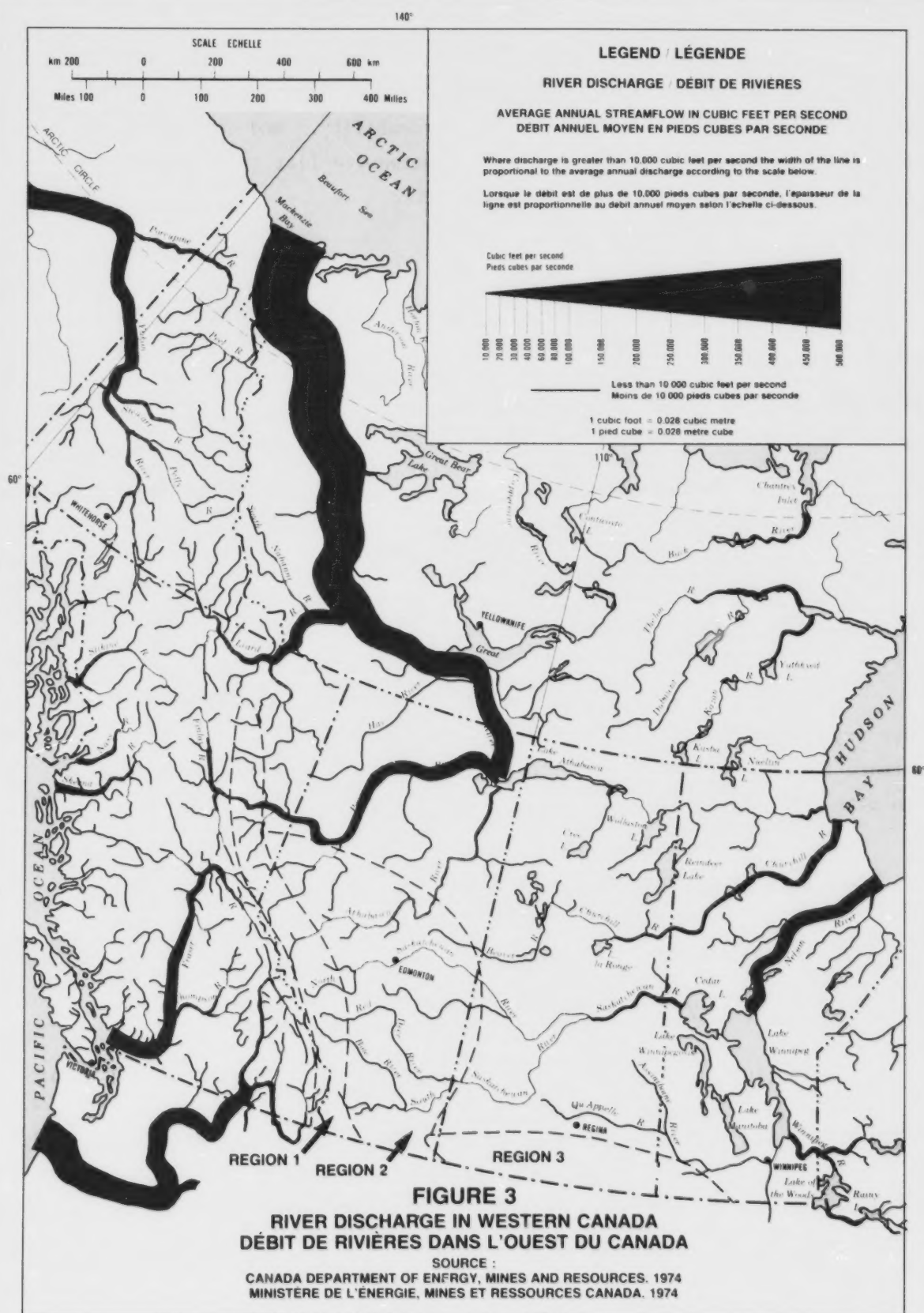
The Foothills generally rise abruptly above the Plains region and are mainly linear ridges and hills with some mountainous parts. The Rocky Mountains rise gradually from the Foothills and form long saddles of mountains with summits from 2000 to 4000 m in elevation. The terrain in all parts of the Rocky Mountains is rugged, having been carved by glaciation from great sections of stratified rocks (Bostock, 1976).

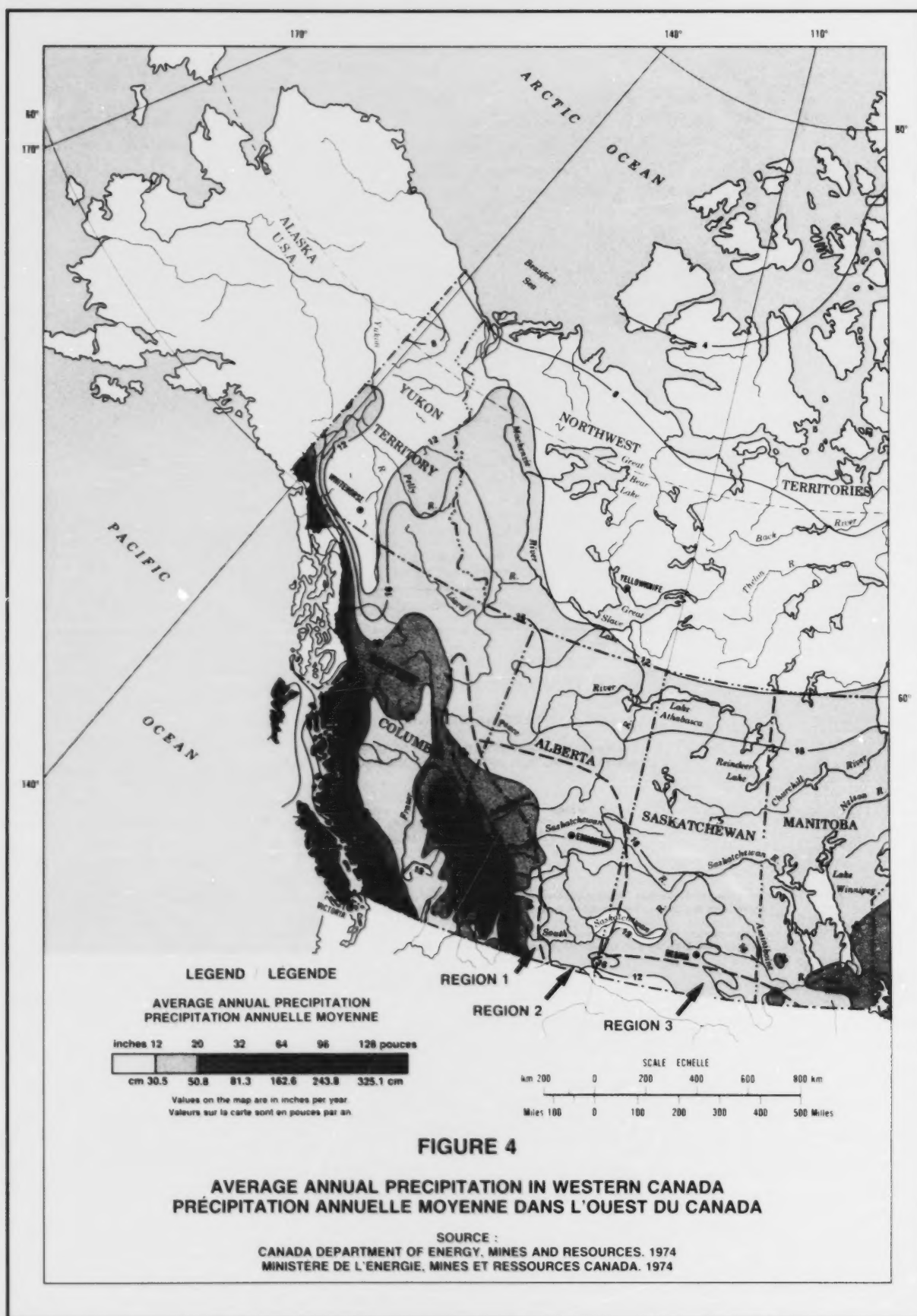
Numerous tributaries of the westward-flowing Columbia and Fraser River systems, the northward-flowing Mackenzie River system, and the eastward-flowing Saskatchewan-Nelson River have their headwaters in the Rocky Mountains (Fig. 3).

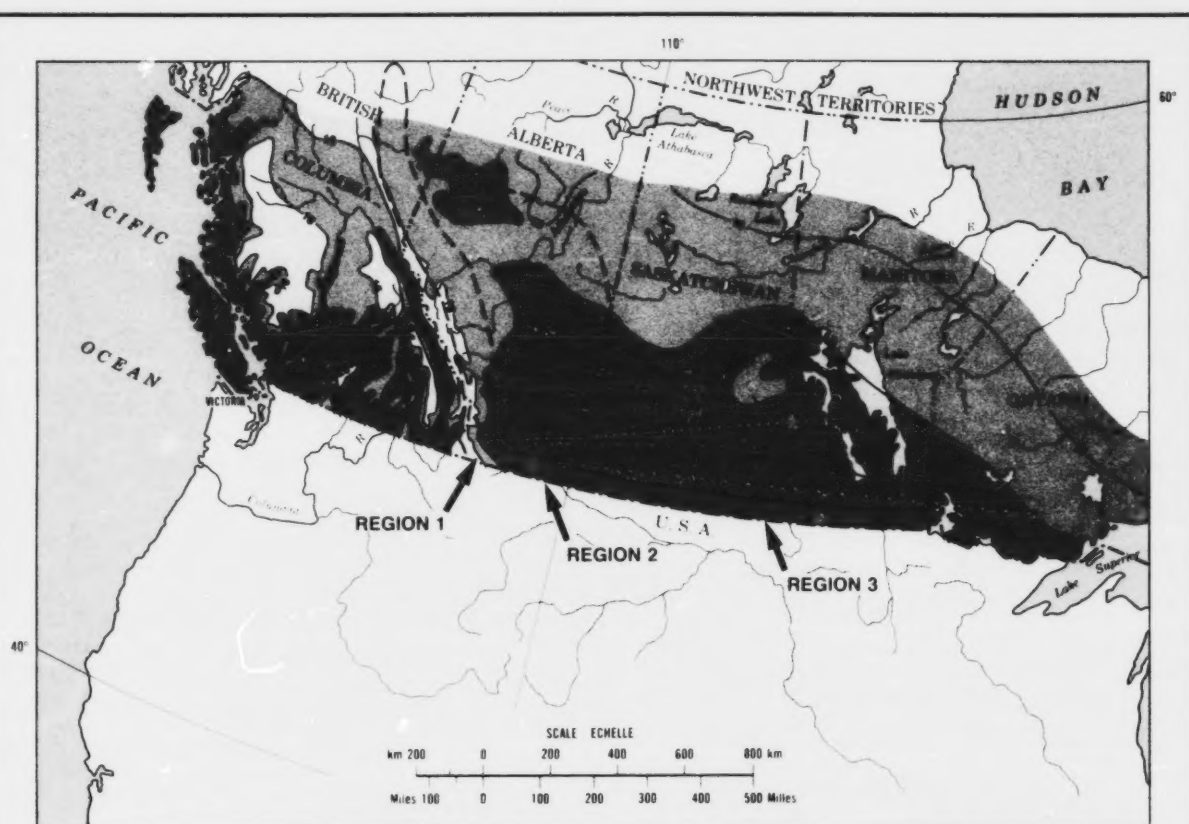
Average air temperatures in July are 12°C and in January are -3°C in the Foothills and -14°C in the mountains.

Precipitation averages 400 mm/yr in the Foothills and 700 mm/yr in the mountains, locally ranging over 1200 (Fig. 4).

Potential evapotranspiration follows a reverse trend to precipitation, with values ranging from 500 mm in parts of the southern Foothills to 350 mm along the northwestern Alberta-British Columbia border (Fig. 5). Because precipitation is relatively high and exceeds potential evapotranspiration in all areas, large quantities of water are available for aquifer recharge and stream runoff (Fig. 6).

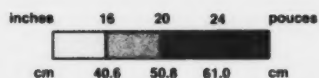






LEGEND / LÉGENDE

AVERAGE ANNUAL POTENTIAL EVAPOTRANSPIRATION ÉVAPOTRANSPIRATION POTENTIELLE ANNUELLE MOYENNE



Potential Evapotranspiration : The potential water loss by evaporation and transpiration from ground and plant surfaces where there is a continuous vegetation cover and sufficient soil moisture for plant use.

Evapotranspiration Potentielle : La perte d'eau potentielle par évaporation et transpiration provenant de la surface du sol et des plantes là où il y a un couvert végétatif continu et suffisamment d'humidité dans le sol pour suffire aux plantes.

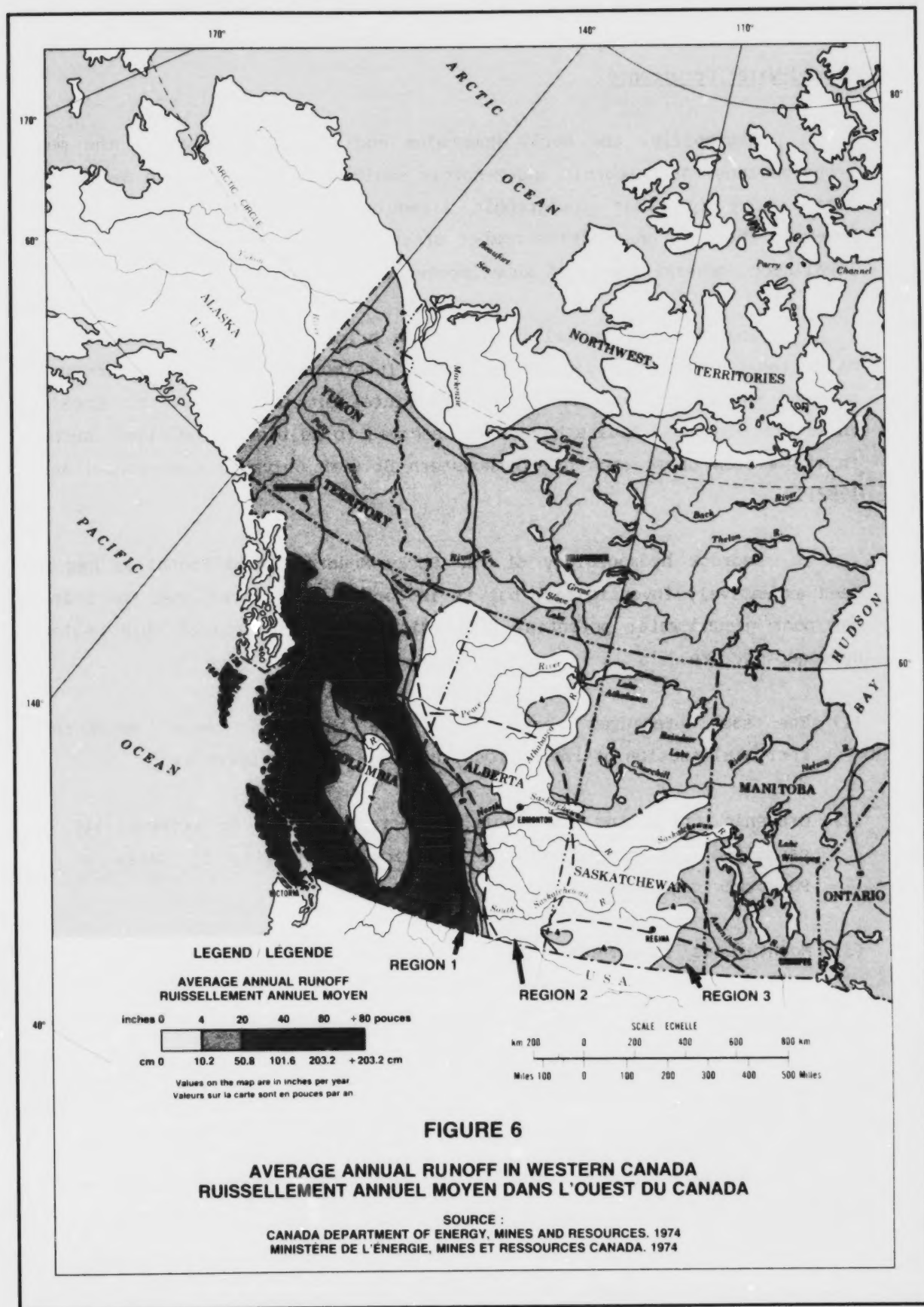
Values on the map are in inches per year.
Valeurs sur la carte sont en pouces par an

FIGURE 5

AVERAGE ANNUAL POTENTIAL EVAPOTRANSPIRATION IN WESTERN CANADA ÉVAPOTRANSPIRATION POTENTIELLE ANNUELLE MOYENNE DANS L'OUEST DU CANADA

SOURCES :

CANADA DEPARTMENT OF ENERGY, MINES AND RESOURCES. 1974
MINISTÈRE DE L'ÉNERGIE, MINES ET RESSOURCES CANADA. 1974



Ground-Water Occurrence

Regionally, the Rocky Mountains and Foothills serve as the major recharge zone for Paleozoic and Mesozoic sediments of the Western Sedimentary Basin. Due to great topographic irregularities throughout the Rockies, however, there is an infinite number of small local flow systems and, in all likelihood, several layers of superimposed flow systems.

Ground water is believed to flow primarily through fractures to a major fault where flow is not impeded. Intermontane valleys in turn drain some of the water from the faults they intersect (Barnes, 1977). Locally, these fractures and faults have been observed to be blocked by clays, such as in the Willow Creek area of northeastern British Columbia (IEC Consultants, 1982).

Bedrock hydrogeology of the Rocky Mountains and Foothills has not been extensively investigated, but it is generally believed that the bedrock has poor ground-water potential. The distinctive features of this region's hydrogeology are

- (1) The same pressures that created the mountains caused metamorphic recrystallization of the bedrock, greatly reducing porosity
- (2) Orogenic fracturing and faulting increased fracture permeability and permitted the development of karstic permeability in parts of the Paleozoic carbonates
- (3) Mountainous topography creates high hydraulic gradients and pressure elevations. With few exceptions, wells in bedrock in this region generally produce flows of less than 0.5 L/s. Higher yields have been measured in coal of the Gates Member (Petro-Canada, 1981), and rates of up to 75 L/s have been measured at springs flowing from karstic carbonates in topographic lows.

The Rocky Mountains are being aggressively weathered, primarily by mechanical processes. The resulting sediments have accumulated to

thicknesses greater than 100 m in intermontane valleys and include talus, landslide debris and alluvial fans. These deposits often contain layers of clean gravel and typically produce flows of 8 to 40 L/s (Barnes, 1977; Ozoray and Barnes, 1978).

Ground-Water Quality

Ground waters in the Rocky Mountains and Foothills are typical of the recharge zones. The major constituents of water in the recharge zones are Ca^{2+} , Mg^{2+} , HCO_3^- , CO_3^{2-} and total dissolved solids range from 50 to 500 mg/L. In some discharge areas, such as the hot springs in Banff, Alberta, carbonate waters of Mississippian and Devonian origin have high temperatures and sulphide minerals (SO_4^{2-} , H_2S , Na^+) which increase total dissolved solids to 2000 mg/L.

The quality of water flowing through the coals in the region is not known. Surface water in the vicinity of coal mines in northeastern British Columbia is hard (100 to 230 mg/L CaCO_3), alkaline, and contains Ca^{2+} , Mg^{2+} , HCO_3^- and 20 to 40 mg/L SO_4^{2-} (IEC Consultants, 1982). These are consistent with regional values. It can be assumed that because the coals in this area have low sulphur content and are generally acid-consuming, water flowing through the coals will be chemically similar to surface waters.

Hydrogeology of Coal Deposits

Coal deposits in northeastern British Columbia behave as aquifers, whereas in southeastern British Columbia, they behave as aquicludes. Coals in northeastern British Columbia are highly fractured, and high yields have been attributed to increased permeability from fracturing. Springs have often been observed at the base of coal seams. Hydraulic parameters for the Gates Member coals and overlying sediments at Petro-Canada's proposed Monkman Mine are listed in Table 1. These values are similar to those of a moderately good aquifer such as silty sand.

Table 1. Hydraulic Parameters of the Gates Member and Overburden at the Monkman Mine Site, Northeast British Columbia

Parameter	Range	Average
Sandstones and coals		
Transmissivity	3.0×10^{-4} to $1.5 \times 10^{-3} \text{ m}^2/\text{s}$	Average $7.0 \times 10^{-4} \text{ m}^2/\text{s}$
Storage coefficient	2.0×10^{-4} to 1×10^{-2}	Average 8.0×10^{-3}
Hydraulic conductivity from pump tests (favoured results)	4.3×10^{-6} to $2 \times 10^{-5} \text{ m/s}$	Average $1.0 \times 10^{-5} \text{ m/s}$
Hydraulic conductivity from falling head tests (less favoured results)		Average $1.3 \times 10^{-6} \text{ m/s}$
Siltstones and shales		
Hydraulic conductivities from falling head tests	5.8×10^{-9} to $1.3 \times 10^{-8} \text{ m/s}$	
Glacial and lacustrine sediments		
Hydraulic conductivities from grain size analysis		
Till	$1.0 \times 10^{-6} \text{ m/s}$	
Lacustrine/fluvial	$1.0 \times 10^{-7} \text{ m/s}$	

Source: Petro-Canada (1981).

Coals of southeastern British Columbia and the Rocky Mountains of southwestern Alberta behave as aquicludes. Springs have been observed at the top surface of coal seams (S. Samuelson and T. Keigan, Westar Mining Ltd., Sparwood, B.C., pers. comm., 1983). The overburden has been shown to have high permeability, possibly higher than the underlying coal, thereby making the coal a confining layer, or aquiclude.

Under some conditions coal is hydrophobic to water. During a recent visit to the Harmer Mine at Sparwood, British Columbia, the senior author

(C. Carr) observed a puddle of rain water repelled by powdered coal; the water was not infiltrating or being absorbed by the coal. However, the water content of the coal at Harmer Mine doubles from 2% *in situ* to 3.5% or 4% before it reaches the preparation plant (G. Nicolson, Westar Mining Ltd., Sparwood, B.C., pers. comm., 1983). This suggests that coal readily takes on atmospheric moisture.

REGION 2

Surface Water Environment

The Plains of Alberta extend from the flanks of the Foothills to the Saskatchewan border. The surface of the plains is relatively even, with a few widely separated groups of low hills such as the Cypress Hills in the southeast, Porcupine Hills in the southwest, and Wintering and Hand Hills to the east of Calgary. Much of the Plains region is about 760 m in elevation, river valleys are entrenched 60 to 120 m, and hills rise to 1000 m or more (Bostock, 1976).

Drainage in the Plains region is dominated by the eastward-flowing Saskatchewan-Nelson River system. The northern part of the region is drained by the northward-flowing Peace and Athabasca rivers. The southern extreme of the region is drained by tributaries of the Missouri River system, notably the Milk River (Fig. 3).

Air temperatures in the region range from $\pm 2^{\circ}\text{C}$ in January to $+18^{\circ}\text{C}$ in July. Annual precipitation decreases in an easterly direction from between 500 and 800 mm to less than 400 mm. In some sections of southeastern Alberta, less than 300 mm of precipitation is expected annually (Fig. 4). Annual potential evapotranspiration increases in an easterly direction from 400 to 550 mm (Fig. 5). High potential evapotranspiration and high temperatures, in combination with low precipitation, have created dry and, in some areas, semi-arid conditions over a large part of the region.

Ground-Water Occurrence

Regional ground-water flow direction is east-northeast from the recharge zone in the mountains and Foothills of Region 1, through deep confined sedimentary rocks of the Western Canada sedimentary basin, to discharge zones in Saskatchewan and Manitoba.

Several intermediate and local flow systems occur above the regional flow systems. These are recharged by topographic highs such as the Cypress Hills. Little elevation is required for recharge. The proportion of recharge area decreases eastward because of fewer topographic highs and decreasing precipitation.

Bedrock in Region 2 is made up of a sequence of thick, laterally continuous flat-lying sedimentary rocks which provide a significant water storage capacity. Because recharge is primarily from the topographically higher mountains and foothills to the west, hydraulic gradients are high.

The best bedrock aquifers are the Horseshoe Canyon coals (yielding 2 to 8 L/s), Paskapoo sandstone (yielding 8 to 35 L/s), Millet sandstone (Edmonton Formation) (yielding 7.6 L/s) and Milk River sandstone (yielding 0.4 to 4.0 L/s) where flowing wells are commonly found. Detailed hydrogeological information is included in Appendix A.

Surficial deposits in Region 2 are primarily clay-rich tills. These deposits are poor aquifers, but due to the characteristic variability of till, there are many small sand aquifers suitable for farm water supply.

Less common glacial deposits in the region which consistently make good aquifers are

- (1) Sands and gravels filling preglacial valleys
- (2) Glacial outwash
- (3) Intertill sand and gravel lenses.

Recent deposits of river alluvium also make good aquifers.

Preglacial valley sands and gravels are the most important surficial aquifers in Region 2. Approximately 30 to 50 deep bedrock channels were infilled by sands, gravels, silts and clays, forming highly permeable narrow conduits up to 100 km in length. Lateral and vertical variations in lithology result in large variations in sustainable yield. Sands and gravels typically yield 5 to 10 L/s, but yields of greater than 40 L/s have been recorded in southwestern Alberta where proximity to mountains has provided clean coarse clastics and a high hydraulic head. Wells tapping these deposits are often free-flowing (Tokarsky, 1974). Preglacial valleys infilled with silts and clays, such as the Cereal Valley east of Red Deer, may be completely dry (Borneuf, 1979).

Glacial outwash deposits of stratified sands and gravels cover limited areas of Region 2. Yields of 0.4 to 2.0 L/s were obtained from an outwash deposit near Medicine Hat, Alberta (Stevenson and Borneuf, 1977).

Intertill sand and gravel lenses are also uncommon in Region 2. A large intertill deposit in the Wabamun area west of Edmonton has yielded 2 to 8 L/s (Ozoray, 1972).

Alluvial deposits composed of permeable sands and gravels occur close to many of the larger rivers in Region 2 and are readily recharged from these rivers. Yields generally increase in proportion to the saturated thickness of the alluvium. The Oldman, Crowsnest, South Saskatchewan, and sections of the Medicine Hat and Red Deer rivers are reported to have alluvial deposits yielding greater than 8 L/s and ranging up to 40 L/s (Tokarsky, 1971, 1974; Stevenson and Borneuf, 1977).

Ground-Water Quality

The quality of ground water in the Alberta Plains region is generally good, but there is a trend toward decreasing quality from west to east. Specific problems in the region are

- (1) High nitrate levels at shallow depths in all parts of the region
- (2) Iron and fluoride levels locally exceeding recommended drinking water standards in the western part of the region
- (3) Sulphide and sodium levels and alkalinity which may exceed recommended drinking water standards in the eastern part of the region (Hackbarth, 1975).

In the bedrock aquifers of the region total dissolved solids generally increase with depth and age of formation. The concentration of total dissolved solids in ground water ranges from less than 100 mg/L in recharge areas of the Paskapoo Formation (sandstone) to greater than 4000 mg/L in the eastern part of the Milk River Formation (sandstone). The major determinant of total dissolved solids in the deeper bedrock is the amount of shale present. Shales decrease ground-water velocity, permitting greater times for aquifer dissolution; shales also have a larger portion of loosely bonded ions. Ion content varies locally and there is a slight trend in chemical constituents with Ca^{2+} , HCO_3^- and CO_3^{2-} in waters to the west and Na^+ and SO_4^{2-} in waters to the east.

Little is known about the quality of ground water in coals of the region. Although water quality is thought to be generally good, recent hydrogeological studies have provided conflicting evidence. Ozoray (1972) reports that water in the coal-rich Horseshoe Canyon Formation contains Na^+ and HCO_3^- with total dissolved solids concentrations of less than 100 mg/L; locally, SO_4^{2-} is the dominant anion. In contrast, Borneuf (1972, p. 7) reports that wells in coal seams near Drumheller have "fairly good yields but the water quality is quite poor."

Water quality in surficial deposits is generally very good where there is moderate flow. The concentration of total dissolved solids tends to increase eastward. Concentrations can be very high when ground-water flow is sluggish such as in clay-rich tills, particularly those in the east and those overlying shales. In recharge areas total dissolved solids concentrations are less than 1500 mg/L with Ca^{2+} , Mg^{2+} and HCO_3^- as the dominant ions; in the intermediate flow systems and discharge areas concentrations increase and Na^+ , SO_4^{2-} and Cl^- become the dominant ions.

In the eastern part of the region pronounced discharge areas, such as springs, seeps and "soap holes," are often surrounded by deposits of gypsum (CaSO_4) (Borneuf, 1972). In a slough near Drumheller, Borneuf (1979) measured total dissolved solids of 300 000 mg/L with high concentrations of sodium, magnesium, sulphates and chlorides (in decreasing order).

Hydrogeology of Coal Deposits

Ground-water flow through coals of the Alberta Plains is better understood than in the Rockies. It is well known that coals are aquifers and that the yield of the aquifer is controlled by the degree of fracturing. The degree of fracturing controls permeability, thereby controlling hydraulic conductivity, sustained yield, and local flow direction. In the Horseshoe Canyon Formation in the Edmonton area, where the hydrogeology of coals is best known, fracture permeability decreases with depth. Differential fracturing may be the result of greater stresses exerted by glaciers overriding coal located on topographic highs or by isostatic rebound of the bedrock under glacial valleys due to unloading of sediments (Stein, 1982). The greatest degree and depth of fracturing occurs along the banks of the preglacial Vegreville buried valley, 20 km southeast of Edmonton, where coal seams at depths greater than 75 m commonly yield 2 to 8 L/s.

Table 2. Hydraulic Parameters of the Horseshoe Canyon Formation in the Edmonton Area

Parameter	Range	Average
Fractured coals		
Transmissivity	7×10^{-5} to $8 \times 10^{-3} \text{ m}^2/\text{s}$	Average $1 \times 10^{-3} \text{ m}^2/\text{s}$
Hydraulic conductivity	2×10^{-5} to $3 \times 10^{-3} \text{ m/s}$	Average $5 \times 10^{-4} \text{ m/s}$
Sustainable yield	2 to 8 L/s	1/3 of yields > 8 L/s
Unfractured coals		
Transmissivity	1×10^{-7} to $2 \times 10^{-6} \text{ m}^2/\text{s}$	
Sustainable yield	0.1 to 0.4 L/s	

Sources: Stein (1982); Ceroici (1979).

Pump tests from coal aquifers in the Edmonton area produced the hydraulic parameters listed in Table 2. The fractured coals have a good capacity to produce water, approximately equivalent to that of a clean sand, whereas the unfractured coals have one and half to three orders of magnitude less capacity to produce water, approximately equivalent to that of a silt.

Region 3

Surface Water Environment

Region 3 is a strip, 150 km wide, in southern Saskatchewan and Manitoba which extends from the Alberta/Saskatchewan border into southwestern Manitoba (Fig. 1). It is gently undulating and rolling, and its surface ranges from 450 to 800 m above sea level with relief about 90 m in the hillier parts (Bostock, 1976). Turtle Mountain in Manitoba rises to a height of approximately 250 m above the surface of the plains. The top of the mountain is dotted by over 50 small lakes, most of which have no surface drainage.

Drainage in the region is dominated by the southward-flowing tributaries of the Missouri River basin and by the southward and eastward-flowing Souris River and its tributaries. A few rivers drain northward out of the region to form part of the Saskatchewan-Nelson system.

River discharge in the region is low or intermittent, and average annual streamflows are less than $28 \text{ m}^3/\text{s}$.

Southern Saskatchewan has a dry climate with only 300 to 400 mm of precipitation annually and potential evapotranspiration of 550 mm (Figs. 4 and 5). The 150- to 200-mm excess potential evapotranspiration minimizes runoff and ground-water recharge at all times of the year except spring (Fig. 6). During spring potential evapotranspiration is lower than the annual average, and an abundance of water from snowmelt and precipitation is available for ground-water recharge.

Turtle Mountain receives approximately 500 mm of precipitation annually and has a potential evapotranspiration of 570 mm.

Ground-Water Occurrence

The hydrogeology of Region 3 is similar to that of the Alberta Plains region. Regional flow passes east-northeast through the deep formations (greater than 300 m) to discharge along their erosional edges in northern Saskatchewan and central Manitoba. Total dissolved solids are generally high, reflecting the large distance to the major recharge area in the Foothills. Shallower formations, most of which are unconsolidated, are recharged only during spring runoff due to low precipitation and high evapotranspiration. Recharge areas are more difficult to identify in Saskatchewan and Manitoba because of the lack of topographic variation. The Cypress Hills, Wood Mountain and Turtle Mountain are proven recharge areas for local and possibly intermediate flow systems.

Within the *bedrock* of the Saskatchewan and Manitoba region there is no zone capable of producing 8 L/s of water with total dissolved solids less than 4000 mg/L. A few formations within 300 m of the surface can meet the yield requirements of a major aquifer but have been eliminated from major aquifer status due to high total dissolved solids.

The Blairmore Group, which is continuous from British Columbia to Manitoba, may be of interest for water storage by means of artificial recharge. In Manitoba, it is known as the Swan River Group and is one of the most continuous and permeable units in the region. Yields commonly are 1 to 5 L/s but range up to 15 L/s (Rutulis, 1982). Hydraulic conductivities of 3.5×10^{-4} m/s have been recorded (Saskatchewan-Nelson Basin Board, 1972). Total dissolved solids range from 5000 to 10 000 mg/L in Manitoba (Rutulis, 1982).

Other less deep formations that may be of interest for low yield exploitation are the Judith River Formation (transmissivity 8.2 to 10.5×10^{-5} m²/s [Whitaker, 1981]), the Frenchman Formation (maximum yield 4 L/s [Whitaker, 1967]), and the Ravenscrag Formation.

Major ground-water withdrawals from the region are not likely to cause subsidence. During glaciation the underlying sediments were repeatedly

subjected to high compressive pressures and were consolidated by an amount greater than any stress that could be created by aquifer development (Saskatchewan-Nelson Basin Board, 1972).

Surficial deposits of the Empress Formation may be the only major aquifers in the Saskatchewan and Manitoba region. The Empress Formation consists of long, narrow and continuous sand and gravel deposits filling preglacial and glacial valleys. These deposits drain overlying sediments and the adjacent bedrock. The Estevan Valley aquifer, the Weyburn Valley aquifer and the Ravenscrag Formation are in hydraulic continuity and form the Estevan aquifer system. The net ground-water yield for this system has been estimated at 430 L/s (Saskatchewan-Nelson Basin Board, 1972).

The Estevan Valley aquifer drains the adjacent area into the Souris River northwest of the town of Estevan. Net ground-water yield for this aquifer has been estimated at 500 L/s. The average concentration of total dissolved solids has been estimated at 1770 mg/L (Saskatchewan-Nelson Basin Board, 1972). Tritium data indicate that recharge of the Estevan Valley aquifer is from precipitation, but the rate of recharge is unknown.

The Weyburn Valley aquifer is made up of longitudinally continuous sand and gravel deposits overlain by till; these deposits have infilled a glacial meltwater valley incised in shale of the Bearpaw Formation. Two years of production pumping at 40 L/s has not brought equilibrium to a well located in the Weyburn Valley aquifer.

Hydraulic parameters are not available for the Ravenscrag Formation aquifer.

Ground-Water Quality

The usefulness of many of the water-bearing units in the region is limited by high levels of total dissolved solids which often exceed the 500 mg/L drinking water standard (Health and Welfare Canada, 1978). Water quality data for southern Saskatchewan indicate an increase in total dissolved solids with depth and from west to east. Values taken from Whitaker (1967, 1974a, 1976) include the following:

Formation	Total dissolved solids (mg/L)
Judith River	<2000 to >6500
Bearpaw	Average 1170
Frenchman	300 to 5350
Ravenscrag	260 to 3570 average 1000
Cypress Hills	Average 310
Empress	Estevan Valley aquifer average 1770
Empress	Weyburn Valley aquifer average 2370

Iron levels of 2.1 mg/L have been measured in water of the Estevan Valley aquifer (Christiansen and Parizet, 1961). These levels are well above the drinking water standard for iron (0.3 mg/L) and indicate a potential ground-water quality problem.

Hydrogeology of Coal Deposits

The hydrogeology of coal deposits in Region 3 is not well known. According to Whitaker (1967, 1974a,b), both the sand and lignitic coal beds of the Ravenscrag Formation can yield variable amounts of water but average only 0.5 L/s. However, in a study of the hydraulic properties of coal and related materials in North Dakota by Rehm *et al.* (1980), much higher hydraulic conductivities were determined for coals similar to those found in Region 3. It is possible that given the high hydraulic conductivity values reported by Rehm *et al.* (1980), the coals in Region 3 can probably yield greater amounts of water than indicated by Whitaker (1967, 1974a,b). Rehm *et al.* (1980) maintain that fractures are the only cause of permeability in coal.

SUMMARY

A broad regional overview of surface and ground-water resources has been presented. No attempt has been made to assess the total amount of surface and ground water available in each region. From this review and from water demand information provided in Part A of this report, it is concluded that adequate supplies of water are available for current and planned coal industry activities in Region 1 but not in parts of Regions 2 and 3 where supplies are low or where there is competition among users.

Table 3. Summary of Coal and Ground-Water Resources

	Region 1	Region 2	Region 3
Coal rank	Bituminous	Subbituminous	Lignite
Coal age	Lower Cretaceous Upper Jurassic	Upper Cretaceous Lower Tertiary	Tertiary
Inferred reserves	71 x 10 ⁹ tonnes	102 x 10 ⁹ tonnes	3.4 x 10 ⁹ tonnes
Mining method	Open pit, underground	Open pit, strip	Strip, open pit
Area (approximate)	80 000 km ²	300 000 km ²	74 000 km ²
Topography	Mountains, foothills	Plains	Plains
Precipitation (average) (annual)	400-1000 mm/yr	300-600 mm/yr	250-500 mm/yr
Evapotranspiration (average) (annual)	350-500 mm/yr	400-550 mm/yr	500-600 mm/yr
Major aquifers(>8 L/s)	>30	>50	1
Maximum well yield	8-1000 L/s	8-50 L/s	40 L/s
Major aquifer types	Alluvial and colluvial gravels and sands; Paleozoic karstic carbonates	Tertiary and Cretaceous sand- stones and coals Preglacial buried valley alluvium	Preglacial buried valley alluvium

Surface and ground-water resources and the major coal fields and active coal mines in Western Canada are indicated on Figure 2. Not all high-yielding aquifers are identified because of the scale of the map and the need for more site specific information. Coal and water resource information for each region is summarized in Table 3.

In Region 1 there are numerous small, fast-flowing streams and rivers which provide large volumes of good quality water. In addition, there are many high-yielding alluvial, colluvial and karstic aquifers of limited extent but high recharge capability evenly distributed throughout the region (Fig. 2). Further ground-water investigations in Region 1 will probably reveal the location of many more high yield aquifers than are currently recorded.

In Region 2, the ability of surface and ground-water resources to meet water supply needs decreases eastward. The surface water system, which consists primarily of a network of eastward-flowing rivers, currently accounts for approximately 95% of total water use in Alberta (Prairie Provinces Water Board, 1984). These heavy demands on surface water resources and the fact that over 88% of river water in the Prairies originates in the Rocky Mountains (Ziemkiewicz, 1983) have resulted in a rapid eastward decrease in surface supplies (Fig. 3).

The ability of ground water to provide a supply of water also decreases eastward in Region 2 because the number of aquifers decreases and yields are lower.

For future coal industry development in Region 2, the combined use of surface and ground water may be the most effective, with a trend toward the use of ground water in the eastern part of the region.

There are no major rivers or other natural water bodies and only one major aquifer in Region 3. At the Poplar River Mine in the Willow Bunch Coalfield, a major reservoir was recently constructed on the East Poplar River to supply water to the Poplar River thermal electric generating station.

The only major aquifer in Region 3 is located adjacent to the Estevan Coalfield, making it the ideal source of water for development in the area. The Cypress, Wood Mountain and Turtle Mountain coalfields have limited water supplies.

Deep, permeable sands and sandstones in the Prairies are not considered to be aquifers because of poor water quality. However, further hydrogeological exploration of these units may reveal potable water supplies.

Influence of Coal Mining and Preparation on Ground Water

There are few data with which to assess the effects of coal mining and preparation on ground water in Western Canada. Based on experience in the United States, however, it is possible that current and planned coal mining development in Western Canada may result in changes in the quantity and quality of water in the mine areas. Alteration to the surface and ground-water regimes is a major concern, particularly in Saskatchewan and Alberta (Regions 2 and 3) where development is in basins that are already or may become water short.²

The following sections review the impact of coal mining on the distribution and quality of surface and ground water before development of a mine, during the mining process and after the mine has been abandoned. In Part A of this report, the quantities of water required for current and planned coal mining and preparation in the study area have been estimated, and existing and potential water supply problems identified.

Water quality problems generally associated with coal mining, namely acid mine drainage, are minimal in Western Canada because of the low sulphide content of the coals and the high carbonate content, and therefore, buffering capacity, of the till overburden. In turn, the maintenance of neutral to high pH in mine drainage prevents the desorption of metal ions from coal and alleviates the problem of heavy metals leaching. However, there may be local surface and ground-water quality impacts, particularly during the mining and post-mining stages.

² Water short, as defined by the Prairie Provinces Water Board (unpub. rep., 1984), is a condition in which consumptive use in a basin exceeds 50% of either the average supply in the 1976-77 drought years or the lowest recorded annual supply.

PRE-MINING IMPACTS

Surface and subsurface land disturbances as a result of exploration activities and mine site preparation can affect surface and ground water. The nature and degree of these disturbances varies from region to region.

The impacts of pre-mining drilling in Western Canada are not known but may occur given the similarities between ground-water systems in the western coal region of the United States and in the Plains coal regions of Alberta and Saskatchewan. Woessner *et al.* (1979, p. 449) report that when exploratory and mine plan drilling in the western coal region of the United States "perforates shallow and deep ground-water systems in an area, avenues for increased rates of ground-water migration and mixing are created" and "measurable ground-water impacts may occur."

Mine site preparation includes the construction of roadways and coal-processing facilities and the removal of any vegetative cover before making the initial mine cut. Construction increases the potential for erosion and may result in the disruption of natural surface drainage patterns. Steep slopes, moderate rainfall and continuous forest cover in many parts of Region 1 make the potential for erosion much greater than in the relatively flat, dry and unforested plains areas of Regions 2 and 3. The sediments entering surface waters as a result of erosion may stress aquatic life and decrease aesthetic value but should have little impact on ground water quality.

The disruption of natural surface drainage patterns will be most severe in the mountain and Foothills areas of Region 1. The diversion of rivers and streams away from mine sites will alter local ground-water flow patterns.

Pre-mining deforestation is necessary only in Region 1. The influence of changes in evapotranspiration, runoff and soil texture and configuration, as a result of deforestation, on infiltration and therefore recharge is not known. Relative to the eastern Rocky Mountains and Foothills area which acts as a regional recharge area, the total area deforested for coal mining (past and future) is too small to have an effect on regional

flow. Local and some intermediate flow systems, however, may change in both quantity and direction of flow.

IMPACTS DURING MINING

The mining of coal can influence the quantity and distribution of ground water as a result of overburden removal, dewatering operations and water use in the mining and preparation of coal; ground-water quality can be influenced by the discharge of effluents from coal preparation facilities, leakage from ancillary facilities and from the mixing and redistribution of ground water due to dewatering and physical alteration of aquifers (i.e. excavation).

The removal of overburden and subsequent extraction of coal result in the interception of natural ground-water flow and the release of ground water from storage (Woessner *et al.*, 1979). Dewatering is required to lower the elevation of the water table below the lowest level of excavation. Alteration of the water table because of dewatering operations can result in additional ground-water flow to the mine from nearby reservoirs and streams (Woessner *et al.*, 1979). "Eventually a new equilibrium will be established which will control inflow to the mine" (Woessner *et al.*, 1979, p. 449).

According to Grisak (1980, p. 10), dewatering is "generally not seen as deleterious in the Western Canada mountain coal areas (Region 1) since most domestic and municipal water supplies are derived from surface water or wells in the gravel-based flood plains." In many parts of Regions 2 and 3, however, the coal seams are the major sources of domestic water (Ziemkiewicz, 1984). At the Poplar River Mine and thermal electric power station near Coronach, Saskatchewan, it was necessary to deepen or redrill most nearby domestic wells affected by dewatering operations (Grisak, 1980). In contrast, Petro-Canada's proposed Monkman Mine in northeastern British Columbia may require dewatering at a rate of 600 L/s, more than double that required at the Poplar River Mine (Petro-Canada, 1981). Although it is anticipated that the ground-water level at the Monkman Mine will be lowered by up to 100 m and the cone of depression will have a radius of 4 km, water use conflicts should be minimal given the remoteness of the mine site.

In Saskatchewan, mine wastewater discharges and the pumped water from dewatering operations are held in settling ponds prior to discharge into local watersheds (Blakeman, 1980). A major impoundment or settling pond would in most instances result in an increase in the amount of recharge of the underlying ground-water flow regime. In the semi-arid southern prairie regions, increased ground-water recharge would probably be beneficial (Grisak, 1980).

A significant amount of water is used in the mining and preparation of coal, particularly in Region 1 where all mined coal is subjected to wet preparation. The mining and preparation of coal in Region 1 require up to 1.85 m^3 of water per tonne of product coal (see Part A of this report). Although some wet processing of coal may occur in the future in Region 2, all coal currently mined in Regions 2 and 3 is dry-processed and water use is estimated at $0.01 \text{ m}^3/\text{t}$ of product coal (see Part A of this report). Two mines in Region 1 (names withheld for reasons of confidentiality) and the Poplar River Mine in Region 3 receive almost all of their freshwater supplies from ground-water sources; all other mines in the study area rely primarily on surface sources for mine and preparation plant freshwater supplies (see Part A of this report). It is unlikely that water use for coal mining and preparation has a significant impact on ground-water resources in the study area. For a detailed investigation of water supply and demand for the coal industry and for other sectors of the economy, refer to Part A of this report.

There are 12 coal preparation plants in the study area, all of which are located in Region 1. Although most facilities practise 100% recycling of process water, "contaminated water can enter the environment as seepage into local ground-water systems from unlined tailings lagoons and as seepage and uncontrolled runoff from plant site areas, coal storage piles and coarse refuse disposal piles" (Paine and Blakeman, 1983, pp. 3-10). As part of a national coal wastewater study (Paine and Blakeman, 1983), wastewaters from mines and preparation plants in the study area were analyzed for the presence of potential contaminants. Within the study area, samples were taken from the Fording and Luscar (Cardinal River) mines and preparation plants in Region 1, the Highvale Mine in Region 2 and the Blenfait and Poplar River mines in Region 3. The study concludes that "wastewaters from coal

facilities generally satisfy water quality guidelines with respect to the concentration of trace elements, organic compounds and inorganic compounds" but that "future expansion in the coal industry with potential increases in wastewater production may engender possible contamination if environmental safeguards are not instituted" (Paine and Blakeman, 1983, p. 8-1).

There are currently no wet preparation plants in Regions 2 and 3. Impacts on ground-water quality owing to coal operations are primarily related to high concentrations of total dissolved solids. Water draining through surface mine spoil areas usually increases in levels of total dissolved solids. If these waters are permitted to mix with surface or ground-water bodies, deterioration of water quality may occur. The water quality of many aquifers in these regions is marginal, and further deterioration may render the supplies unpotable for domestic use (Grisak, 1980).

In all three regions there is the possibility of surface and ground-water contamination as a result of leakage from ancillary facilities such as settling ponds, coal piles and equipment maintenance sites. In addition, Grisak (1980, p. 16) discusses the possibility of ground-water quality degradation due to the "mixing of ground water layers during the dewatering/mining cycle, resulting in seepage of poor quality water from one stratum into another." In some coal regions of the United States, it has been reported that dewatering has resulted in the upwelling of highly mineralized ground water causing contamination of shallower aquifers.

When used in coal mining operations, blasting agents are a potential source of ammonium nitrate (Paine and Blakeman, 1983). The problem of ground-water contamination by ammonium nitrate is receiving increased attention in Western Canada and the United States. Mine effluent at the West Decker Mine in Montana contained nitrate concentrations ranging from <1 to 100 mg/L (Woessner *et al.*, 1979). High concentrations of ammonia (>7 mg/L) and nitrate (>26 mg/L) were also found in wastewater samples from two mines in Region 1 (Fording River Mine and Cardinal River/Luscar Mine) (Paine and Blakeman, 1983). These concentrations exceed Canadian drinking water quality guidelines for ammonia (≤ 0.5 mg/L) and nitrate (<10 mg/L) (Health and Welfare

Canada, 1978). A serious environmental concern of the proposed Sage Creek Coal Mine in southeastern British Columbia is the potential contamination of surface and ground waters due to the release of nitrates from ammonium nitrate explosives.

POST-MINING IMPACTS

Little is known about post-mining effects on ground water, but it is generally understood that the influence of mine site reclamation and abandonment on the quantity and distribution of ground water depends on the extent of the disturbance to the original flow system, the hydrologic properties of the spoil materials, and the availability of recharge. The quality of post-mining ground water is highly variable depending on "the quality of ground water resaturating the spoils, the amount of recharge from precipitation which has reached the water table and the type, distribution and leachability of spoil materials" (Woessner *et al.*, 1979, p. 451). Post-mining water quality impacts may also occur beyond the mine site.

Once mining operations and reclamation activities at a mine site are completed, a post-mining steady-state ground-water system will ultimately be established. Ground-water supplies that existed in the pre-mining system but have been removed or interrupted to access and mine a coal seam are "virtually irreplaceable" (Grisak, 1980, p. 20). This will be most significant at surface mines in the Plains regions (Regions 2 and 3) where the coal seam itself is often an important aquifer and where recharge from precipitation is low. Conversely, abandoned underground coal mines in Region 2 are believed to be very high-yielding wells. The shafts at these mines have, in effect, become large-diameter wells with several horizontal collector wells radiating into the best aquifers (coal) (Saskatchewan-Nelson Basin Board, 1972). An abandoned underground mine at Lethbridge, Alberta, lies below the Oldman River but is hydraulically connected to it. A transmissivity of the "aquifer" was calculated at $0.10 \text{ m}^2/\text{s}$ with a single point safe yield of 70 L/s (Saskatchewan-Nelson Basin Board, 1972).

The evaluation of post-mining ground-water flow through reclaimed mine spoils can be very complex. Extensive field study and theoretical

modelling of post-mining flow systems and properties of mine spoils have been completed or are underway; most of these studies are in the United States but some work in the Foothills and Plains areas of Alberta (Regions 1 and 2) is currently under investigation by the Alberta Reclamation Research Technical Advisory Committee (Moran *et al.*, 1983; Moran, 1984; Ziemkiewicz, 1984). According to Woessner *et al.* (1979), if only a small portion of a large ground-water flow system has been affected, the direction of flow through the spoils and out of the mine site will be in the same general direction as the larger system. "However, if the mining operation affects the major area of a flow system, post-mining paths may be altered depending on the availability of recharge, and hydrologic properties of the spoils" (Woessner *et al.*, 1979, p. 450).

Large quantities of water are available for aquifer recharge and stream runoff in Region 1, primarily because of high precipitation and low evapotranspiration. The southeastern part of Region 2 and all of Region 3 are semi-arid. An excess of potential evapotranspiration over precipitation minimizes runoff and ground-water recharge at all times of the year except spring; an abundance of water is generally available in the spring for ground-water recharge. The recharge of local flow systems in Regions 2 and 3 is primarily from topographic highs, but the amount of recharge area decreases in an eastward direction because of fewer topographic highs. The lack of topographic variation is most evident in Region 3, and although recharge areas are difficult to identify, the Cypress Hills, Wood Mountain and Turtle Mountain are proven recharge areas for local flow systems.

Changes in the hydraulic conductivity of strip mine spoils relative to pre-mining conditions can be influenced by "the original overburden lithology, methods of stripping the overburden, methods of recontouring the spoils and the time of year stripping and recontouring take place" (Rehm *et al.*, 1980, p. 555). Where the overburden consists mainly of sand or sandstone, the replaced spoils may continue to function as aquifers. Where the overburden is composed primarily of silt, clay and shale, the spoils may behave as an aquitard with hydraulic properties similar to the original overburden (Rehm *et al.*, 1980). By selectively stripping and piling mine spoils according to permeability, they can be replaced in a like manner with

sands first, and confining tills and clays on top. The practicality of such a technique depends on the variability of the overburden. Mines in the United States have reestablished confined aquifers in this manner, thereby causing the least change from pre-mining conditions and preventing a lower hydraulic conductivity throughout the mine (Rehm *et al.*, 1980).

Spoils are replaced using draglines, bulldozers and scrapers. Those replaced by draglines and bulldozers are dumped into place and graded over once; those replaced by scrapers are broken into smaller pieces by the scraper blade and repeatedly compacted as each successive layer is emplaced. As a result, spoils replaced by draglines and bulldozers are generally more permeable. The flow rate through the spoils also depends on the orientation of regional ground-water flow. Maximum flow can occur when the spoil strips are oriented parallel to the ground-water flow (Rehm *et al.*, 1980).

Poorly consolidated and blocky spoils are relatively permeable and generally have a higher hydraulic conductivity than the pre-mining overburden. The creation of blocky spoils is enhanced if stripping or contouring occurs during the winter months because the water in the pores of the sediment freezes (Rehm *et al.*, 1980). In field studies at strip mines in the central part of Region 2, Moran (1984, p. 23) noted that "the combination of fracturing of the spoil mass and ponding of water in low areas allows for extremely rapid influx of water into the spoil mass at rates perhaps 10 to 100 times as fast as in the unmined landscape."

Most coal mines in the mountain area of Region 1 have been operating for less than ten years, and as yet, little is known about post-mining ground-water flow in reclaimed mine areas. It is generally anticipated that hydraulic conductivities of rock waste will be much higher than pre-mining values; the fully lithified overburden will be replaced by very blocky and highly permeable rock waste.

Problems associated with the quality of post-mining ground water have not been extensively investigated at coal mines in Western Canada. As noted earlier, post-mining water quality varies, depending on the quality of ground water resaturating the spoils, the amount of recharge from precipitation, and the type, distribution and leachability of spoil materials.

It is difficult to assess post-mining water quality effects in parts of Region 2 and in Region 3 because "the background water quality is often near the borderline of potable water" (Grisak, 1980, p. 15). Ground water in reclaimed areas of Regions 2 and 3 often exhibits somewhat higher concentrations of total dissolved solids (TDS) than ground water in undisturbed areas (Grisak, 1980). In the central part of Region 2 (Edmonton and Halkirk/Forestburg coal areas), ground-water data from Moran (1984) showed that the potential for contamination of surface water bodies is very low but that significantly degraded water (high TDS) was found migrating laterally from one reclaimed area into adjacent unmined aquifers.

The sulphur content of coals in Western Canada is relatively low (0.2% to 0.6%) and the development of post-mining acid drainage will be neutralized by carbonate-rich surface and ground-water systems in Region 1 and by carbonate-buffered ground-water systems in Regions 2 and 3 (Grisak, 1980). The maintenance of neutral to high pH in mine drainage helps to prevent the desorption of metal ions from coal and alleviates the problem of heavy metals and trace elements leaching.

Post-mining impacts on ground-water quality may occur beyond the mine site and may not appear until many years after reclamation has been completed. According to Woessner *et al.* (1979, p. 451), "poor quality ground water resulting from spoil leaching can degrade downgradient ground water supplies and surface water bodies at points of ground water discharge" and "may also move into underlying ground-water systems if hydraulic conditions permit."

Aesthetic deterioration of surface water has been reported in the Crowsnest Pass area of southeastern British Columbia (Region 1) due to high iron concentrations (30 mg/L) in ground water draining from abandoned surface and underground mines (Grisak, 1980).

In a study of mine spoil water quality in southeastern Montana, where mining conditions and ground-water quality are similar to much of Regions 2 and 3, Van Voast *et al.* (1977) observed more serious deterioration of water quality in old mine spoils (30 years or more) than in young mine spoils (a few years old), compared with undisturbed material.

The contribution of precipitation to the recharge of mine spoils has not been documented. As noted earlier, however, recharge from precipitation is likely to be greater in Region 1 and in the eastern and northern parts of Region 2 than in the semi-arid parts of Regions 2 and 3. In areas of high rainfall the dissolution of salts by the infiltration of precipitation through mine spoils may result in the deterioration of ground-water quality. This may be of particular concern at older mine sites that have not been reclaimed to any extent.

Reclamation of land disturbed by coal operations is required in all parts of the study area. According to Marshall (1983, p. 125), "concurrent reclamation and field research is now being conducted at all surface coal mines in Canada." Yet, there are a number of problems affecting the successful reclamation of individual mine sites and extensive areas of derelict land remain at abandoned mine sites in Western Canada (Marshall, 1982, 1983). Alberta and British Columbia have long-term rehabilitation programs for the cleanup of abandoned coal mining areas; Saskatchewan is concentrating on concurrent reclamation of active mine sites and much of the derelict land may never be reclaimed (Marshall, 1982). According to Sims *et al.* (1984), approximately 75% of all orphan coal mine spoils in Alberta had been reclaimed by the year 1983; the extent of reclamation in British Columbia and Saskatchewan is not known.

Conclusions

In the Rocky Mountains of British Columbia and in the mountains and Foothills of Alberta (Region 1), adequate supplies of surface and ground water are available to meet the predicted needs of coal industry expansion to the year 2000. Current water use in this region is primarily surface-supplied, but high-yielding aquifers have been delineated in all parts of the region and many more are assumed to exist. Bedrock in the region generally has poor ground-water potential, whereas intermontane valley deposits often are good aquifers.

In some basins within the Plains regions of Alberta and Saskatchewan/Manitoba there is not an adequate supply of water for future coal industry development. This is due to low surface and ground-water supplies and competition from other water-using sectors. There are numerous good bedrock aquifers in the Plains region of Alberta (Region 2) and some good aquifers in surficial deposits. Only one major aquifer system exists in surficial deposits in the Plains region of Saskatchewan and Manitoba (Region 3); there are some bedrock aquifers, but yields are low and water quality poor. Future development in the Plains regions may necessitate the combined use of surface and ground-water supplies with a trend toward the use of ground water in Region 3 and in the eastern part of Region 2.

Given the current state of knowledge, it is not possible to provide a complete assessment of the impact of the coal industry in Western Canada on the amount, quality and distribution of ground water.

Although models have been used to predict the impact of coal mining on ground water in the Plains region of Alberta, significant field documentation of such impact has not been obtained. Ground-water impacts can only be predicted based on experience from the United States. Little documentation exists in Canada for three reasons:

- (1) In response to a demand for alternative sources of energy, the coal industry in Western Canada has experienced a period of tremendous growth beginning in the late 1960s; regulatory legislation and supporting environmental study and review processes were hard pressed to keep pace during the initial stages of the resurgence.
- (2) In the major coal-producing regions few pre-mining ground-water investigations had been undertaken with the result that no baseline data were available for comparison with mining and post-mining conditions.
- (3) There has been no long-term field monitoring of ground-water quality and distribution in mining areas and in adjoining unmined areas.

Experience from the United States provides an indication of the potential for ground-water impacts in Western Canada. These impacts are highlighted as follows:

PRE-MINING IMPACTS

- Land surface disturbances, such as deforestation and stream diversion, may alter the quantity and flow pattern of local ground-water systems.
- Increased rates of ground-water migration and mixing may be created if pre-mining drilling penetrates both shallow and deep ground-water systems.

MINING IMPACTS

- Dewatering operations at mines in the plains areas (Regions 2 and 3) may conflict with local domestic water use.
- Wastewater from coal facilities generally satisfies federal water quality guidelines, but future coal industry expansion may result in surface and ground-water contamination unless further environmental safeguards are instituted.
- Ground-water contamination by ammonium nitrate in blasting agents is increasingly a concern.

POST-MINING IMPACTS

- Where a mining operation affects the major area of a flow system post-mining ground-water flow may be altered.
- It may be difficult to assess post-mining water quality impacts in parts of Regions 2 and 3 because of poor background water quality.
- Aquifers in Regions 2 and 3 may become contaminated because of lateral migration of ground water from adjacent reclaimed mine areas.
- Post-mining acid drainage and the leaching of heavy metals and trace elements from coal should not be deleterious in Western Canada.
- Post-mining impacts on ground-water quality may occur beyond the mine site and may not become evident until many years after reclamation has been completed.

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Appendix A
Geology and Hydrogeology



Geology and Hydrogeology

REGION 1: ROCKY MOUNTAINS OF BRITISH COLUMBIA AND MOUNTAINS AND FOOTHILLS OF ALBERTA

The Foothills and most of the eastern Rocky Mountains were formed during the Silurian Caribou orogeny and the Upper Cretaceous - Early Tertiary Laramide (Rocky Mountain) orogeny. These orogenies uplifted, folded and faulted miogeosynclinal deposits that had been accumulating since Cambrian time over what is now the Rocky Mountains and Foothills.

Upper Jurassic

Fernie Formation

The Fernie Formation is made up of marine shale, below which no coal-bearing zones are found.

Nikanassin Formation

A nonmarine sandstone and shale make up this formation. The formation is coal-bearing in the central Rockies.

Kootenay Formation

This is an Upper Jurassic/Lower Cretaceous formation sometimes thought equivalent to the Nikanassin Formation in the southern Rockies. Lithologically, it is a thick-bedded, fine- to coarse-grained, cherty sandstone interbedded with dark shale, siltstone and friable bituminous coal. In southeastern British Columbia, there are up to 14 coal seams from less than 1 m thick to 16 m thick paralleling the Elk River valley; these contain an estimated 36 billion tonnes of recoverable reserves.

Lower Cretaceous

Bullhead Group of Northeastern British Columbia

This group consists of the Gething and Cadomin formations and is mainly an alluvial-deltaic sequence. The Cadomin Formation consists of massive conglomerates from a piedmont-alluvial plain which grade laterally into the overlying Gething Formation. Coal occurs throughout the Gething Formation in 11 known seams with inferred resources of 2.37 billion tonnes (British Columbia Ministry of Mines and Petroleum Resources, 1977).

Blairmore Group of Southeastern British Columbia

Consisting of the Cadomin, Luscar and Mountain Park formations, this group is equivalent to the Bullhead Group and lower Fort St. John Group of northeastern British Columbia. The Luscar Formation consists of non-marine sandstones, shales, conglomerates, and subbituminous coal which is commercially mined throughout the Alberta Foothills.

Fort St. John Group of Northeastern British Columbia

This is an alluvial-deltaic deposit similar to the underlying Bullhead Group. The basal Moosebar Formation is generally an impermeable marine shale, but the uppermost portion, where fractured, discharges water from several springs at 4.5 L/s, presumably draining the overlying Gates Member of the Commotion Formation (IEC Consultants, 1982). The Commotion Formation is deltaic, in which the lowermost member is the coal-bearing Gates Member. Inferred resources of 5.35 billion metric tonnes are found in seams of the Gates Member (British Columbia Ministry of Mines and Petroleum Resources, 1977). The Bullmoose Mine in northeastern British Columbia has five seams totalling 12.5 m of coal in an 80-m section (Teck Bullmoose Coal Inc., 1982); the proposed Monkman mine, also in northeastern British Columbia has 12 seams, 1 to 11 m thick for a total of 21 m of coal in a 65-m section.

Upper Cretaceous

Alberta Group of Southeastern British Columbia

This group is a predominantly marine sequence of shales, hard sandstones and a few siltstones equivalent to the upper Fort St. John Group, Dunvegan Formation and Smoky Group of northeastern British Columbia. The coal-bearing Cardium Formation lies above the Blackstone Formation and below the Wapiabi Formation. All are considered to have low permeability (Tokarsky, 1974) and yield less than 0.5 L/s (Borneuf, 1980).

Smoky Group of Northeastern British Columbia

This group is equivalent to the upper two thirds of the Alberta Group of southeastern British Columbia. The group is divided into five formations including the coal-bearing Cardium Formation. Yields are generally less than 0.5 L/s (Borneuf, 1980).

Brazeau and Wapiti Formations

These are Upper Cretaceous equivalents to the Belly River, Bearpaw and Edmonton formations of the Alberta Plains region. The upper portion of these formations (Edmonton Formation equivalent) is coal-bearing. Being made up of shales, these formations are poor aquifers with yields less than 0.5 L/s (Borneuf, 1980).

Quaternary

Surficial Deposits

These are Quaternary to recent glacial deposits largely reworked into talus, alluvial fan, landslide and river channel deposits. Quaternary fills of preglacial valleys are locally important sources of ground water.

REGION 2: PLAINS OF ALBERTA

The Alberta Plains region is underlain by a sequence of Paleozoic carbonates and shales and Mesozoic sandstones, siltstones, clayshales and coals of the Western Canada Sedimentary Basin. The beds dip uniformly westward and elevation increases westward, so that the total thickness of sediments reaches 5000 m at the western edge of the region.

The Laramide orogeny, which uplifted the Rocky Mountains during the Late Cretaceous-Early Tertiary, created an eastward-oriented drainage system with very deep valleys. In the Quaternary, these valleys were filled with coarse clastics during glaciation to form some of the best aquifers in Western Canada. During the same period most of the Alberta Plains were covered with till.

The Cretaceous and younger formations of the Alberta Plains are described below in order of decreasing age.

Cretaceous

Blairmore Group (Lower Cretaceous)

This group consists of siliceous and calcareous sandstone, green chloritic sandstone, dark carbonaceous and calcareous shale, with conglomerate, coal, and tuff.

Alberta (Colorado) Group (Lower and Upper Cretaceous)

This group is made up of a dark grey fissile shale with sandy shales and chert sandstones. It is generally of low permeability (Tokarsky, 1974).

Milk River (Lea Park, Eagle) Formation (Upper Cretaceous)

This formation is made up of a distinctive white-weathering, variably cemented, fine-grained sandstone with light grey shales and clays and sandy shales. Nomenclature varies greatly with location and date of

investigation. This formation is an aquifer of some importance, being exploited over a 30-m interval at depths of 200 to 300 m (Tokarsky, 1974). Ground water flows north-northeast and is little influenced by topography except near the St. Mary River. Disruption of the pattern of ground-water flow near the St. Mary River may be due to the presence of flowing wells which, by 1960, had resulted in a 30-m drawdown of the potentiometric surface (Meyboom, 1960). Flowing wells yield up to 4 L/s and nonflowing wells from 0.4 to 4.0 L/s; Na^+ and HCO_3^- are the dominant ions with total dissolved solids increasing rapidly due to increasing amounts of shale and proportionate reduction to flow rate. Fluorides reach concentrations of 8 mg/L in Alberta, and although Borneuf (1976) reports that no adverse effects have been observed, there is unconfirmed evidence of tooth malformations in children (S.G. Evans, Geological Survey of Canada, pers. comm., 1985).

Pakowki Formation (Upper Cretaceous)

This formation consists of a dark grey marine shale and sandy shale interbedded with sandstone with a basal chert pebble conglomerate. The formation is of very low permeability.

Belly River Formation (Upper Cretaceous)

This formation is made up of the Foremost and Oldman formations. Lithologically, it is a green-grey shale interbedded with silts, and containing some ironstone and coal. The Oldman Formation occurs in the southernmost plains as a massive bedded, medium- to coarse-grained sandstone with yields of 0.4 to 3 L/s in the Medicine Hat area (Stevenson and Borneuf, 1977). Total dissolved solids concentrations in this area are from 1000 to 2000 mg/L but increase to over 3000 mg/L in the southeast where there is regional flow.

Bearpaw Formation (Upper Cretaceous)

This formation consists of a dark grey marine shale with brown, silty shale and thick zones (2-25 cm) of ironstone. A non-marine grey

sandstone unit up to 210 m thick in the upper part of the Bearpaw Formation is known as the Bulwark Sandstone Member (Borneuf, 1979).

Blood Reserve Formation (Upper Cretaceous)

This formation is a massive, yellow-weathering, grey sandstone which is approximately 30 m thick at the United States border but which pinches out rapidly northward. It is restricted to the southeastern corner of Alberta but is a reasonably good aquifer for farm water supply where the thickness is adequate (Tokarsky, 1974).

Edmonton/Horseshoe Canyon Formation (Upper Cretaceous)

This section has a series of names and systems of subdivision. In southern Alberta, it is divided into the St. Mary River Formation and the Kneehills Formation. The St. Mary River Formation is approximately equivalent to the Eastend Formation (Saskatchewan) and is a hard, green-grey, calcareous sandstone and silty shale, grey shale, coal and limestone up to 150 m thick. The sandstone units are low yield aquifers (less than 2 L/s) (Tokarsky, 1974). The Kneehills Formation is a weathered tuff zone and is approximately equivalent to the Whitemud and Battle formations (Saskatchewan). The lower half of the Kneehills Formation is a white-weathering, clayey sandstone and the upper half a siliceous tuff; total thickness is less than 15 m. The Kneehills Formation is not considered an aquifer.

From Calgary northward this section is commonly known as the Edmonton Formation. It reflects a change in lithology from the unconsolidated sands, clays and tuffs of Saskatchewan and southern Alberta to fractured sandstones, carbonaceous shales and coals. Aquifer yields are highest where the formation is most fractured, ranging from 2 to 8 L/s (Ozoray, 1972).

Farther north and east, the Edmonton Formation becomes increasingly thick and coal rich, whereupon it becomes known as the Horseshoe Canyon Formation. Lithologically, it is a nonmarine, fine-grained, bentonitic

Appendix A
Geology and Hydrogeology

Geology and Hydrogeology

REGION 1: ROCKY MOUNTAINS OF BRITISH COLUMBIA AND MOUNTAINS AND FOOTHILLS OF ALBERTA

The Foothills and most of the eastern Rocky Mountains were formed during the Silurian Caribou orogeny and the Upper Cretaceous - Early Tertiary Laramide (Rocky Mountain) orogeny. These orogenies uplifted, folded and faulted miogeosynclinal deposits that had been accumulating since Cambrian time over what is now the Rocky Mountains and Foothills.

Upper Jurassic

Fernie Formation

The Fernie Formation is made up of marine shale, below which no coal-bearing zones are found.

Nikanassin Formation

A nonmarine sandstone and shale make up this formation. The formation is coal-bearing in the central Rockies.

Kootenay Formation

This is an Upper Jurassic/Lower Cretaceous formation sometimes thought equivalent to the Nikanassin Formation in the southern Rockies. Lithologically, it is a thick-bedded, fine- to coarse-grained, cherty sandstone interbedded with dark shale, siltstone and friable bituminous coal. In southeastern British Columbia, there are up to 14 coal seams from less than 1 m thick to 16 m thick paralleling the Elk River valley; these contain an estimated 36 billion tonnes of recoverable reserves.

Lower Cretaceous

Bullhead Group of Northeastern British Columbia

This group consists of the Gething and Cadomin formations and is mainly an alluvial-deltaic sequence. The Cadomin Formation consists of massive conglomerates from a piedmont-alluvial plain which grade laterally into the overlying Gething Formation. Coal occurs throughout the Gething Formation in 11 known seams with inferred resources of 2.37 billion tonnes (British Columbia Ministry of Mines and Petroleum Resources, 1977).

Blairmore Group of Southeastern British Columbia

Consisting of the Cadomin, Luscar and Mountain Park formations, this group is equivalent to the Bullhead Group and lower Fort St. John Group of northeastern British Columbia. The Luscar Formation consists of non-marine sandstones, shales, conglomerates, and subbituminous coal which is commercially mined throughout the Alberta Foothills.

Fort St. John Group of Northeastern British Columbia

This is an alluvial-deltaic deposit similar to the underlying Bullhead Group. The basal Moosebar Formation is generally an impermeable marine shale, but the uppermost portion, where fractured, discharges water from several springs at 4.5 L/s, presumably draining the overlying Gates Member of the Commotion Formation (IEC Consultants, 1982). The Commotion Formation is deltaic, in which the lowermost member is the coal-bearing Gates Member. Inferred resources of 5.35 billion metric tonnes are found in seams of the Gates Member (British Columbia Ministry of Mines and Petroleum Resources, 1977). The Bullmoose Mine in northeastern British Columbia has five seams totalling 12.5 m of coal in an 80-m section (Teck Bullmoose Coal Inc., 1982); the proposed Monkman mine, also in northeastern British Columbia has 12 seams, 1 to 11 m thick for a total of 21 m of coal in a 65-m section.

Upper Cretaceous

Alberta Group of Southeastern British Columbia

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sandstone unit up to 210 m thick in the upper part of the Bearpaw Formation is known as the Bulwark Sandstone Member (Borneuf, 1979).

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From Calgary northward this section is commonly known as the Edmonton Formation. It reflects a change in lithology from the unconsolidated sands, clays and tuffs of Saskatchewan and southern Alberta to fractured sandstones, carbonaceous shales and coals. Aquifer yields are highest where the formation is most fractured, ranging from 2 to 8 L/s (Ozoray, 1972).

Farther north and east, the Edmonton Formation becomes increasingly thick and coal rich, whereupon it becomes known as the Horseshoe Canyon Formation. Lithologically, it is a nonmarine, fine-grained, bentonitic

sandstone and silty shale with lenticular coal beds, bentonite beds, siderite lenses and calcareous cement. The major subbituminous coal beds which are mined throughout central Alberta occur in the lower 150 m of the Horseshoe Canyon Formation. The formation is characterized by great lateral and vertical variability, resulting in equally variable aquifer characteristics. Thick sand beds, called the Millet Sandstone Member, and an unnamed basal sandstone are extensive and permeable enough to be major aquifers. The Millet Member southeast of Edmonton yields a minimum of 7.6 L/s (Ceroici, 1979).

North of the North Saskatchewan River, the Bearpaw Formation, which separates the Horseshoe Canyon and Belly River formations, pinches out and the latter two formations become increasingly difficult to distinguish. The resulting sequence of sandstones, shales and coals is called the Wapiti Formation. Typically, it is a poor aquifer yielding less than 2 L/s (Barnes, 1977).

Lower Tertiary

Paskapoo (Willow Creek) Formation

This Paleocene formation is the uppermost bedrock unit in the Western Canada Sedimentary Basin. It has a maximum thickness of 1800 m in the Foothills west of Red Deer and thins progressively updip to an arcuate erosional edge 200 km east of the Foothills. It is a nonmarine, grey, fine- to medium-grained, cherty, calcareous sandstone, siltstone and shale with minor conglomerate, limestone, coal and tuff beds. Sandstone units are the major aquifers over much of central Alberta, yielding from 0.1 to 8 L/s. Yields of 8 to 35 L/s are common in the Wabamun (Pembina oilfield) and Edmonton areas (Ozoray, 1972; Ceroici, 1979) but have also been obtained in the Red Deer and Drumheller areas (LeBreton, 1974; Borneuf, 1972). Permeability of the Paskapoo Formation is due to fracturing (Barnes, 1977), although LeBreton (1974) reports that the Paskapoo sands are friable southwest of Red Deer. The Scollard Member identified in the Edmonton area includes three economically exploitable coal zones which are 46 m deep. These coal zones are not extensively fractured and yield 0.4 to 2.0 L/s

(Ceroici, 1979). Springs have been observed issuing from the Paskapoo Formation, the most prolific flowing at an average of 8 L/s near Rocky Mountain House (Tokarsky, 1971). Water quality is generally good with total dissolved solids concentrations less than 500 mg/L and less than 100 mg/L in recharge areas near the Foothills; HCO_3^- , CO_3^{2-} , Ca^{2+} , and Mg^{2+} are the dominant ions with SO_4^{2-} and Na^+ increasing eastward.

Cypress Hills Formation

This formation is made up of Eocene quartzite and chert gravel interbedded with sands, silts, and clays. It occurs as outliers on the highest parts of the Cypress Hills. The hydrogeology of this formation is described at the end of Appendix A.

Quaternary

Surficial Deposits

Quaternary tills cover all of the Alberta Plains region with the exception of the Cypress and Porcupine Hills which are not glaciated. Sorted Quaternary sediments including preglacial valley fill, glacial outwash and intertill deposits make satisfactory aquifers. The only recent deposits of significance lie along major river channels.

REGION 3: PLAINS OF SASKATCHEWAN AND MANITOBA

Saskatchewan and Manitoba contain the eastern part of the Western Canada Sedimentary Basin with its series of continuous, gently dipping sedimentary rocks onlapping the Precambrian crystalline rocks to the northeast. In the Turtle Mountain area, the dip is 0.3 to 1.0 m/km southwest. The northwest trending axis of the Williston Basin passes 120 km south of Regina, increasing the thickness of sediments and the percentage of evaporites in the otherwise uniform and continuous Western Sedimentary Basin. The northernmost part of the Basin axis takes a westerly turn and becomes the Moose Jaw Syncline.

During Upper Cretaceous time, southern Saskatchewan and Manitoba experienced a broad uplift resulting in a new drainage pattern and extensive deposition of nonmarine sediments. This drainage pattern is well preserved in many areas in the Cypress Hills, and subsequent drainage systems tend to follow the same pattern.

The Precambrian crystalline basement is overlain by approximately 900 m of Paleozoic carbonates, the surface of which is deeply weathered in places. The large hiatus from Mississippian to Jurassic time is overlain by both clastic and evaporite deposits of Jurassic through Early Tertiary (Paleocene) age. Formations occurring in the upper 300 m of southern Saskatchewan are listed below, in order of decreasing age.

Cretaceous

Swan River (Blairmore) Group (Lower Cretaceous)

This group is made up of a fine- to coarse-grained, subrounded, quartz sand with silts and clays, which are locally carbonaceous. This well-sorted, uniform, continuous sand stretches across the region, subcropping below drift in northern Saskatchewan.

Lea Park Formation (Upper Colorado Group) (Upper Cretaceous)

This formation includes the Milk River Formation and is known as the Eagle Formation in Alberta. Lithologically, it is made up of grey, noncalcareous silty clay and clay; the lower part contains abundant calcareous foraminifera and thin argillaceous limestone beds.

Pakowki Formation (Upper Cretaceous)

This formation consists of a noncalcareous silty clay and clayey shale, locally bentonitic and concretionary.

Judith River (Belly River) Formation (Upper Cretaceous)

This is a deltaic deposit equivalent to the Oldman and Foremost formations of Alberta and includes the Ribstone Creek Tongue (McLean, 1971). This formation is made up of nonmarine, calcareous clays, silts and fine to very fine, poorly sorted, angular sands.

Hydraulic parameters measured from pump tests are typical of silty sand: transmissivities of 8.2 to $10.5 \times 10^{-5} \text{ m}^2/\text{s}$ corresponding to hydraulic conductivities of 4.6 to $5.8 \times 10^{-6} \text{ m/s}$. A storage coefficient of 5.2×10^{-4} was calculated but may be unreliable due to the presence of gas in the water (Whitaker, 1981).

According to static water levels, ground water in the Judith River Formation of southwest Saskatchewan has a downward gradient, flows northeast from the Cypress Hills and radially from the Bowdoin Dome; this indicates that recharge is taking place over both topographic highs (Whitaker, 1981).

Potable water is available from sand lenses in the Judith River Formation. South of the Cypress Hills the concentration of total dissolved solids in ground waters is greater than 200 mg/L ; ground water with concentrations less than 2000 mg/L is generally available north of the Cypress Hills. Total dissolved solids concentrations increase with depth to a maximum of 6500 mg/L . This increase in TDS is accompanied by a change in dominant ions from Ca^{2+} , + Mg^{2+} to Na^{+} , and from HCO_3^{-} + SO_4^{2-} to SO_4^{2-} + Cl^{-} (Whitaker, 1981).

Bearpaw Formation (Saskatchewan) (Upper Cretaceous)

This formation is the Upper Cretaceous equivalent to the upper part of the Riding Mountain Formation of Manitoba. Lithologically, the Bearpaw Formation is made up of a grey, noncalcareous, silty clay and clay; locally, the formation is bentonitic and concretionary, including several sandy clay and sand beds of large areal extent (Cruickshank, Demaine, Matador and Outlook members) which pinch out eastward and have been eroded over the

Sweetgrass Arch to the west. The Bearpaw (Riding Mountain) Formation subcrops under glacial drift throughout most of the region.

The extreme southwest corner of Saskatchewan locally uses ground water from the Bearpaw Formation for domestic supplies. Water is taken from thin but continuous sand beds and from areas where the upper surface of the formation is extensively fractured along subcrops below drift. No yields have been recorded for either the sands or the shales; yields in the shales are often too low to support a domestic water supply. The total dissolved solids concentrations of eight water samples taken from shales of this formation averaged 1170 mg/L; Na^+ , SO_4^{2-} and HCO_3^- were the dominant ions (Whitaker, 1976).

Except in the southwest corner of Saskatchewan, Bearpaw Formation sediments are not considered aquifers, but the water-bearing capacity of the sand beds improves westward into Alberta.

Boissevain Formation (Manitoba)

This formation is an equivalent of the Upper Cretaceous sands, silts and shales of the Eastend, Whitemud, Battle and Frenchman formations of Saskatchewan and Alberta. It has a total thickness of 30 m. Locally, it is used for small yield domestic water supply.

Eastend Formation (Saskatchewan) (Upper Cretaceous)

This formation is made up of a thin, fine-grained sand and silt, locally carbonaceous or calcareous. It has been eroded over Bowdoin Dome westward, subcrops near the Manitoba border and escaped glacial erosion at Turtle Mountain in Manitoba where it is considered part of the Boissevain Formation.

Whitemud Formation (Saskatchewan) (Upper Cretaceous)

This formation is made up of a thin kaolinitic sand, silt and clay, locally carbonaceous. It has the same distribution as the Eastend Formation.

Battle Formation (Saskatchewan) (Upper Cretaceous)

This formation consists of a thin silt and clay shale, locally bentonitic or carbonaceous. It has the same western extent as the Eastend Formation but is much more limited eastward.

Frenchman Formation of Saskatchewan (Upper Cretaceous)

This formation is made up of a thin interbedded sand, silt, and clay locally bentonitic, carbonaceous, concretionary or calcareous. It covers approximately the same area as the Eastend Formation.

Where the sands of the Eastend, Whitemud, Battle and Frenchman formations occur near the surface in southern Saskatchewan, ground water yields are typically 0.5 L/s and are primarily used for domestic purposes. An exception exists in the town of Assiniboia where 4.0 L/s is produced (Whitaker, 1967). The concentration of total dissolved solids in the ground water of these formations ranges from 300 to 5350 mg/L; concentrations seem to increase eastward. The dominant ions in the ground water are Na^+ , HCO_3^- and SO_4^{2-} (Whitaker, 1967, 1974a,b, 1976).

Tertiary

Ravenscrag Formation of Saskatchewan (Paleocene)

This is an interbedded unit with sand, silt, clay and lignite seams, locally carbonaceous, concretionary or calcareous. The occurrence of the Ravenscrag Formation is restricted to the Williston Basin, glacial remnants in the Cypress Hills, and as the Turtle Mountain Formation in Turtle Mountain, Manitoba. It subcrops over the southeast corner of Saskatchewan. This formation is the source of all coal (lignite) mined in Saskatchewan and Manitoba. Both sand and lignite beds are considered aquifers, with yields averaging 0.5 L/s. Water quality is reasonably good; the concentration of total dissolved solids ranges from 260 to 3370 mg/L and averages 1000 mg/L (Whitaker, 1967, 1974a,b).

Cypress Hills Formation (Eocene)

This formation is made up of a quartzite and chert gravel interbedded with sand, silt and clay, conglomerate zones with carbonate cement and bentonitic beds. This section includes the Swift Current beds and reworked Cypress Hills sediments and only occurs as outliers on the highest parts of the Cypress Hills in southwest Saskatchewan.

This blanket of coarse-grained clastics perched on top of topographic highs is totally unconfined and well drained by peripheral springs at the base of the formation. Ground water yields in the Cypress Hills Formation are dependent on annual recharge, with hydraulic heads declining markedly during periods of drought. The total dissolved solids concentrations of 13 water samples taken from this formation averaged 310 mg/L; Ca^{2+} , Mg^{2+} and HCO_3^- were the dominant ions.

Empress Group

The Empress Group is made up of all gravel, sand, silt and clay deposits beneath the drift mantle in southern Saskatchewan; they span Late Tertiary to Quaternary age. These deposits are less than 30 m thick over most of southern Saskatchewan and Manitoba, but reach thicknesses of more than 100 m where they have infilled preglacial valleys. The group consists of two main units, a basal quartzite and chert gravel known as the Saskatchewan Gravels in southern and central Alberta, and an upper interbedded gravel, sand, silt and clay (Whitaker and Christiansen, 1972).

Quaternary

Undifferentiated Quaternary Glacial Deposits

These Quaternary deposits consist mainly of grey and brown calcareous till including clay, silt, sand and gravel, 0 to 120 m thick. Large vertical and lateral variations make this unit a poor aquifer. Coarse-grained lenses are of local importance, especially stratified drift occurring between tills (and glacial episodes) (Saskatchewan-Nelson Basin Board, 1972).

Appendix B
Stratigraphy of Western Canada

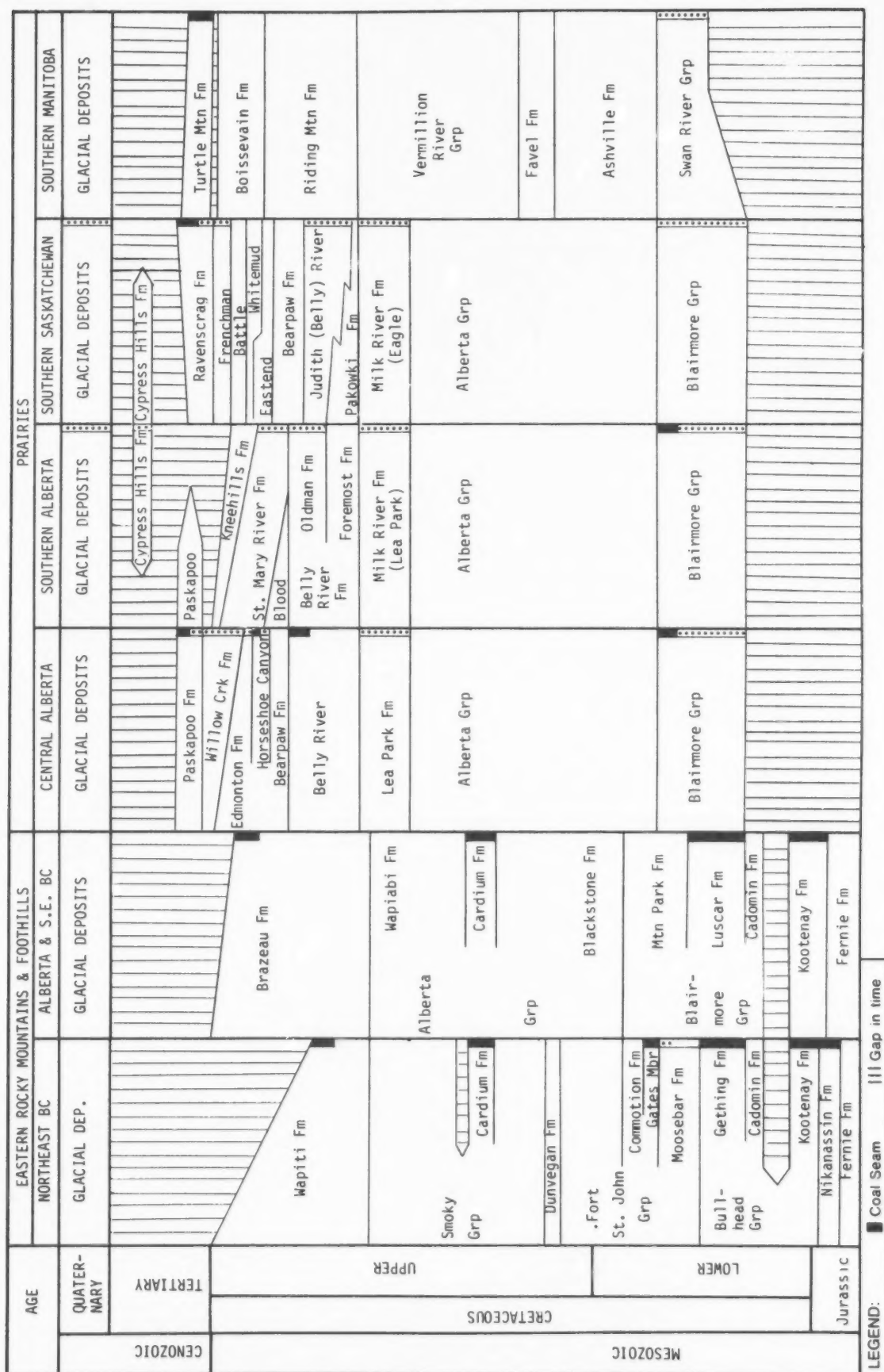
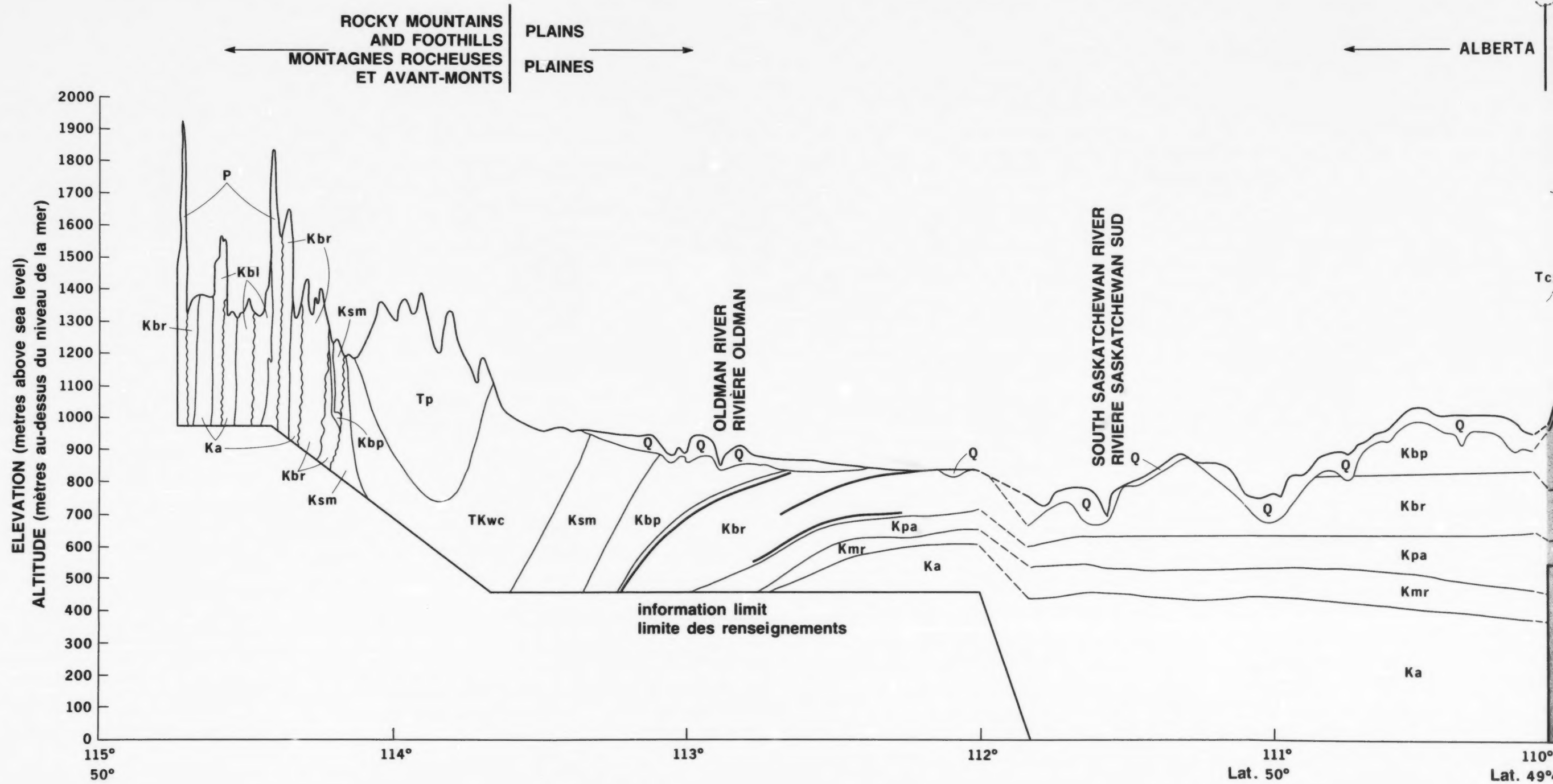


Figure B-1. Stratigraphy of Western Canada.



Appendix C
Stratigraphic Cross Section of Western Canada



NORTH-SOUTH SECTION
ALONG
ALTA.-SASK. BORDER
SECTION NORD-SUD
LE LONG DE LA FRONTIÈRE
ALBERTA-SASKATCHEWAN

← ALBERTA

SASKATCHEWAN →

October 1983
Cynthia H. Carr

October 1983
Cynthia H. Carr

Quaternaire
Groupe Empress

Q
Qe

Quaternary
Empress Group

Formation Cypress Hills
Formation Wood Mountain
Formation Ravenscrag

Tcy
Twm
Tr

Cypress Hills Formation
Wood Mountain Formation
Ravenscrag Formation

Formation Porcupine Hills
Formation Willow Creek

Tp
TKwc

Porcupine Hills Formation
Willow Creek Formation

CYPRESS HILLS

SALT SOLUTION COLLAPSE
AFFAISSEMENT DE SOLUTION SALINE

buried valley aquifer
nappe aquifère enfouie de la vallée

WOOD MOUNTAIN
MONT WOOD

EAST POPLAR RIVER
RIVIÈRE EAST POPLAR

Tcy

Tr

Kf,e

Q

Kbp

Kbp

Kf,w,e

Kbp

Tr

Twm

Tr

Kf,w,e

Tw

Kbp

Kbr

Kpa

Kmr

Ka

Kjr

Kpa

Kmr

Kbp

Kjr

Kpa

Kmr

Kbp

Kbr

Kpa

inf
lim

110°45'
Lat. 49°45'

110°
Lat. 49°

109°

108°

107°

106°

October 1983
Cynthia H. Carr

October 1983
Cynthia H. Carr

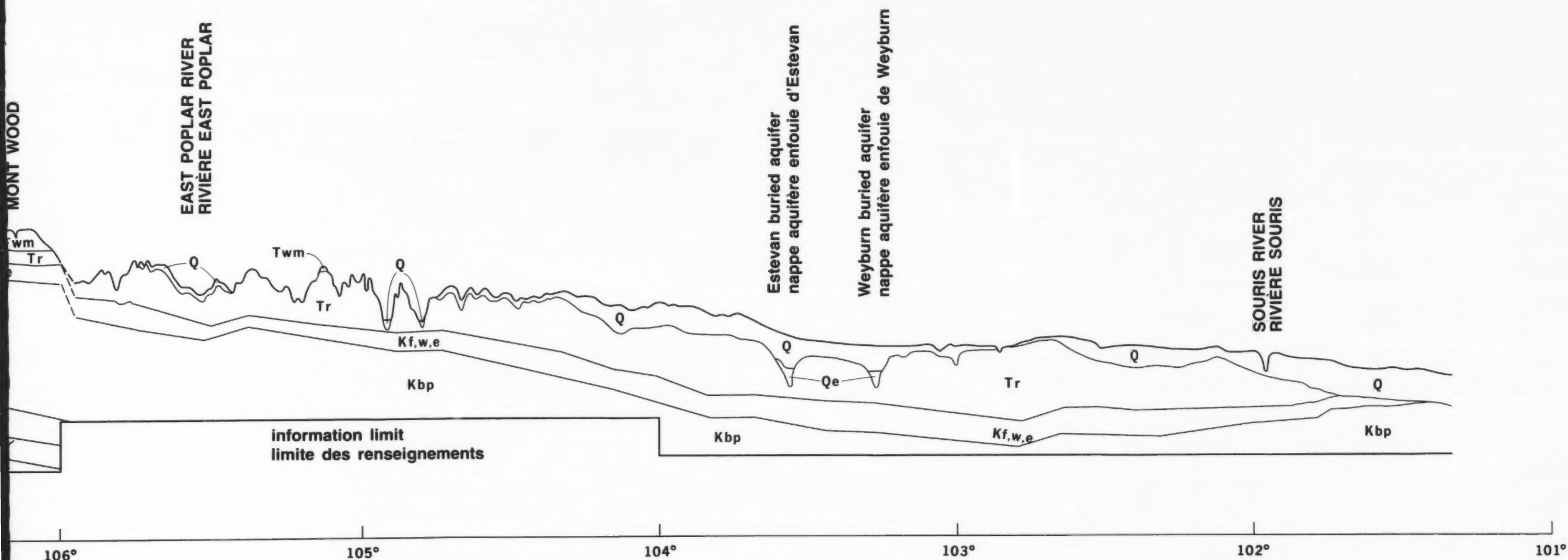
Échelle verticale 1:12,000
Échelle horizontale 1:250,000
Exagération verticale approx. 20×

Vertical scale 1:12,000
Horizontal scale 1:250,000
Vertical exaggeration approx. 20×

Appendix C
STRATIGRAPHIC CROSS SECTION OF WESTERN CANADA
Annexe C
SECTION TRANSVERSALE STRATIGRAPHIQUE
DE L'OUEST DU CANADA

Quaternary	Q	Quaternary	Formations Frenchman, Whitemud, Eastend	Kf,w,e	Frenchman, Whitemud, Eastend Formations
Empress Group	Qe	Empress Group	Formation St. Mary River	Ksm	St. Mary River Formation
			Formation Bearpaw	Kbp	Bearpaw Formation
Cypress Hills Formation	Tcy	Cypress Hills Formation	Formation Belly River ou Judith River	Kbr,jr	Belly River or Judith River Formation
Wood Mountain Formation	Twm	Wood Mountain Formation	Formation Pakowki	Kpa	Pakowki Formation
Ravenscrag Formation	Tr	Ravenscrag Formation	Formation Milk River	Kmr	Milk River Formation
			Groupe Alberta	Ka	Alberta Group
Porcupine Hills Formation	Tp	Porcupine Hills Formation	Groupe Blairmore	Kbl	Blairmore Group
Willow Creek Formation	TKwc	Willow Creek Formation	Paléozoïque	P	Paleozoic
			Couche de charbon	—	Coal Seam

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MAPS NOT

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CARTES

OMISES